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Seafood Sustainability

Series I

Edited by

Naresh C. Pradhan, Junning Cai and Stephen M. Stohs

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Preface to ”Seafood Sustainability—Series I”

The importance of seafood sustainability is ever-growing. The recent COVID-19 pandemic has heightened awareness about the importance of maintaining a secure, sustainable seafood supply. This Special Issue on seafood sustainability sought papers that identify the successful drivers of sustainable seafood production and consumption, including issues in marine capture fisheries and aquaculture. Seafood sustainability is a broadly encompassing area. This Special Issue series contains ten papers covering topics on trends in consumer preferences for seafood produced sustainably, aspects of anthropogenic effects on certain fish species, nutritional importance of fish in school meals, gender role and community planning towards sustainable fisheries, and resource allocation issues in aquaculture. The study areas extend to a diverse range of geographic locations, covering North America, Europe, Australia, Asia, and Africa. We believe that the papers in this series help to provide a better understanding of seafood sustainability. We offer our special thanks to Professor Emeritus PingSun Leung of the University of Hawaii for taking the initiative to propose this Special Issue and to the staff in the Sustainability journal editorial office for providing all the support and coordination needed to publish this volume.

Naresh C. Pradhan, Junning Cai, Stephen M. Stohs
Special Issue Editors

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Article

The Sustainable Seafood Movement Is a Governance Concert, with the Audience Playing a Key Role

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Abstract: Private standards, including ecolabels, have been posed as a governance solution for the global fisheries crisis. The conventional logic is that ecolabels meet consumer demand for certified "sustainable" seafood, with "good" players rewarded with price premiums or market share and "bad" players punished by reduced sales. Empirically, however, in the markets where ecolabeling has taken hold, retailers and brands—rather than consumers—are demanding sustainable sourcing, to build and protect their reputation. The aim of this paper is to devise a more accurate logic for understanding the sustainable seafood movement, using a qualitative literature review and reflection on our previous research. We find that replacing the consumer-driven logic with a retailer/brand-driven logic does not go far enough in making research into the sustainable seafood movement more useful. Governance is a "concert" and cannot be adequately explained through individual actor groups. We propose a new logic going beyond consumer- or retailer/brand-driven models, and call on researchers to build on the partial pictures given by studies on prices and willingness-to-pay, investigating more fully the motivations of actors in the sustainable seafood movement, and considering audience beyond the direct consumption of the product in question.

Keywords: corporate social responsibility; ecolabels; ethical consumption; green marketing; supply chain management; sustainable seafood

1. Introduction

With seafood being the most highly traded food globally and per capita consumption increasing more rapidly than other animal proteins, wild capture fisheries face real and imminent environmental limits. According to widely cited FAO reports, harvest rates have stagnated over the last two and a half decades and the number of fish stocks fully exploited or overexploited has progressively increased [1].

In the past, calls for better management of the oceans generally only involved the catching sector and governments, but recently more widely recognised scarcity in the supplies of some species, driven by overfishing, is being scrutinised by a wider audience [2]. There is now a global discourse on seafood sustainability that is the focal point of environmental non-government organization (ENGO) campaigns, supply chain procurement decisions, (inter-) governmental management strategies, and consumer decision-making. New innovative governance arrangements—often centred around market transactions—are emerging that involve governments, markets, fishers and aquaculture producers, ENGO and media actors, as well as consumers, in what is commonly referred to as the sustainable seafood movement [3–5]. Aquaculture is part of this discourse, and indeed as an alternative source of supply is often a part of the solution for the overfishing problem. Aquaculture has its own set of sustainability concerns including pollution from feed and waste and escapes of aquaculture animals into wild populations [6]. More generally, in food production, sustainability concerns include carbon footprint, other types of pollution, and the materials used in packaging. For manageability, in this paper, the scope is limited to overfishing and therefore, wild capture fisheries.

There is not yet clear evidence that the sustainable seafood movement in the form of ecolabels has effectively reduced overfishing. Marine Stewardship Council (MSC)-certified fisheries have been found to be less likely to be doing harmful fishing than non-MSC-certified fisheries [7]. On the other hand, there are other studies pointing to the failings of seafood ecolabels [8]. Overfished stocks and fisheries without suitable data for determining overfishing are certified as sustainable by prominent ecolabels [9]. The MSC system for dealing with information challenging certification appears to have serious flaws [10]. Ecolabels do not deal with important ecological impacts from fishing, such as fuel use, pollution from anti-fouling agents, and post-harvest processes [11]. MSC certification has been found to encourage collective action to promote sustainability, but on the other hand has also been found to be difficult for smaller scale and developing country operations to access due to the expense and nature of reporting required [12]. While the direct effect of ecolabels on fisheries certified is not clearly positive, ecolabels are now an established feature of many seafood markets and seem likely to remain so in the short- to medium-term. It is therefore important to keep researching the sustainable seafood movement to better understand its potentials and limitations.

Since it emerged in the late 1990s, the sustainable seafood movement has been characterised by constellations of actors tackling issues of sustainable production and consumption. It is one part of the broader environmental movement and consists of organisations seeking to conserve fisheries and marine ecosystems primarily through the use of market-based approaches. Companies involved in fishing, processing, wholesaling and retailing seafood are increasingly concerned about the risks to their investments and public profile and are responsive to adopting these approaches. Campaigns of ENGOs, some of which have included shaming companies seen as doing the "wrong thing", have been key drivers in this concern about risk. While not all marine conservation organisations use market-based approaches, the sustainable seafood movement has become a prominent component of marine conservation efforts in North America and Europe.

The sustainable seafood movement has a presence also in many other markets. Two examples include the Southern African Sustainable Seafood Initiative [13] and the 'I'm FINished with FINS' anti-shark finning campaigns for Singapore and Hong Kong [14]. The sustainable seafood movement has to date been a stronger influence on markets in some countries than others. Globalization, including of social movements, does not manifest homogeneously in every location around the world, rather, global phenomena are localised [15]. Local histories of concern about environmental damage vis a vis industrial development, the presence of environmental protection stories in local language media, the political history of relations between government, industry and environmental activists in different countries all create path dependencies. Globalization of the sustainable seafood movement does not mean that all countries around the world will follow the same pattern of ecolabeling, wallet cards and celebrity chef activities that have occurred in the UK or the USA. The messages of transnational ENGOs are received differently by different populations, and local NGOs may take the cause up differently. Local food cultures and consumer concerns also affect the effectiveness of sustainability messaging [16–19].

There is a growing body of research examining the activities of key actor groups in the sustainability movement, with the role of consumers portrayed in various ways. The sustainable seafood movement has targeted informed consumers as "agents of societal change" for decades [20]. The idea of consumers driving sustainability improvements by "voting with their wallets" has been the focus of both academic and marketing research, which has centred on green or ethical consumerism through willingness-to-pay studies and examining the use of price premiums for ethically labelled products to confer economic benefit for doing the "right thing" [21]. The assumption is that price premiums or procurer preferences for ecolabels will incentivise more sustainable fishing practices or management [22–24]. This tendency has been conceptualised as a logic model by Alexis Gutierrez and Thomas Thornton [25] (see Figure 1.)

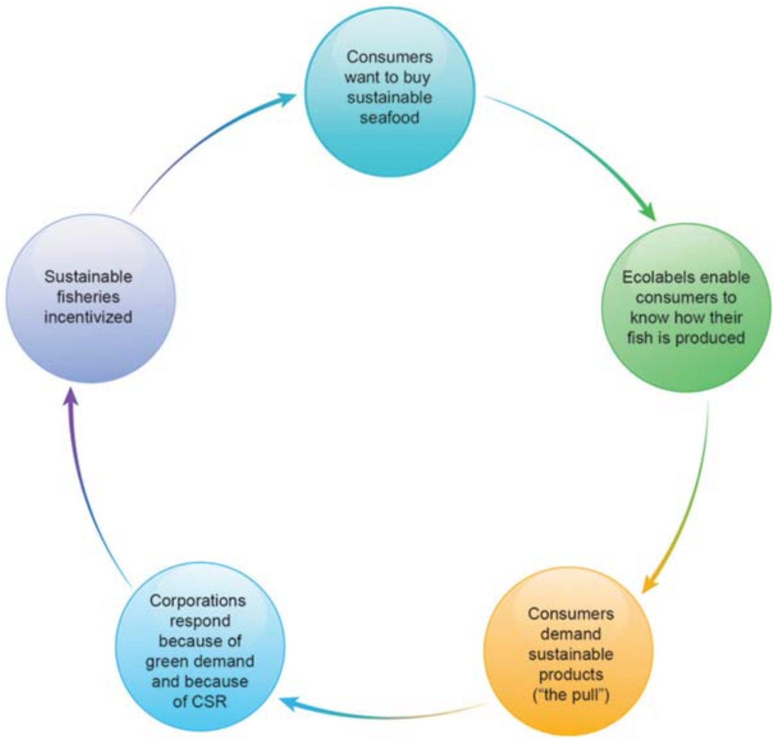

Figure 1. Consumer-driven logic for ecolabels. Source: Gutierrez and Thornton [25].

Notwithstanding the prevalence of this logic model, some researchers question the efficacy of consumer-oriented research tools [25] and price incentives [26]. An "attitude–behaviour gap" has been used to describe how, in the case of sustainable food consumption, attitudes alone are often a poor predictor of how consumers will behave at the checkout [27]. These researchers found that while consumers placed importance on seafood sustainability, this was not reflected in their fish consumption patterns nor in their general attitudes about eating fish, leading them to conclude that ethical considerations about environmental stability do not significantly shape fish consumption behaviour [28]. Recent survey and interview research with consumers in the USA on their values around seafood including willingness to pay a premium for product certified as sustainable showed that sustainability was less important than price, even when consumers said sustainability was important to them [29]. Beyond the seafood sector, there is also research showing weak consumer demand in other sustainability movements [21,30,31].

Since the sustainable seafood movement continues to grow, with market-based interventions influencing nearly 25% of wild-caught seafood globally [32], drivers other than direct consumer demand must be operating. Retailers, brands and fishing companies continue to invest in sustainable seafood certification and sourcing. Gutierrez and Thornton [25] assert that seafood ecolabel markets are not driven by consumer demand but by the interactions of social movement organisations, states, consumers and companies. According to Gulbrandsen [33], it is the same situation for forestry ecolabels. Rather than responding to consumer demand, retailers and brands are responding to pressure coming from the environmental movement, both through campaigning and increasingly through company-NGO partnerships. Fishers are incentivised to seek certification so as to improve or maintain market position or achieve price premiums. ENGOs also partner fishing enterprises to encourage them to achieve certification [34]. By this logic, ecolabels operate along the lines of Figure 2.

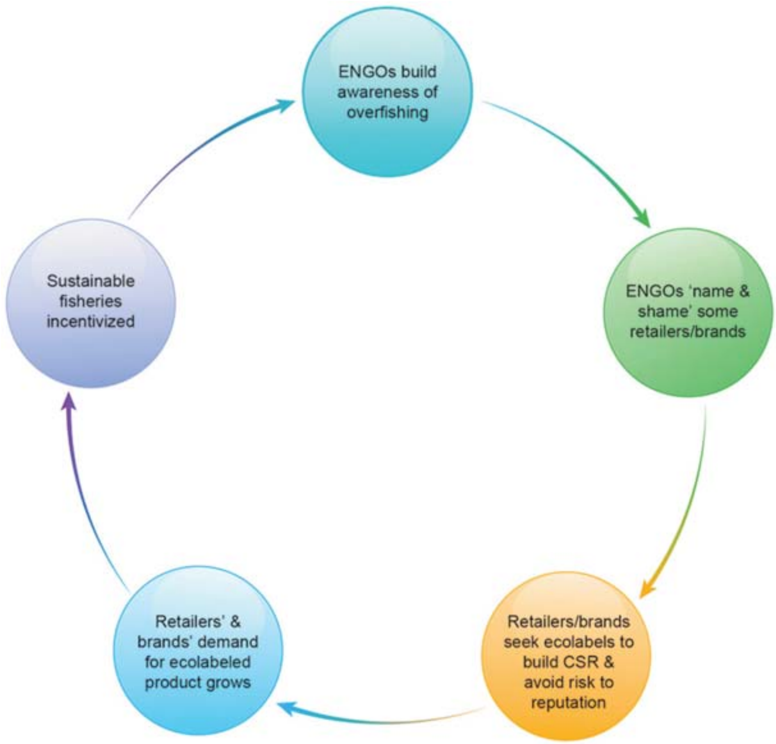

Figure 2. Retailer/brand and environmental non-government organization (ENGO)-driven logic for ecolabels.

Although the dynamics between retailers and the environmental movement are certainly a key factor behind the sustainable seafood movement, we argue that it is not enough to replace the consumer-driven logic with a retailer/brand-and-NGO-driven logic. In the first logic, consumers are inaccurately depicted, and in the second they are left out entirely. Are consumers really unimportant in the sustainable seafood movement? To whom are ENGOs doing the naming and shaming? Retailers and brands are concerned about their reputation with whom? We find that consumers play a role as audience for ENGOs' naming and shaming performances, which then pushes brands/retailers to pursue sustainable procurement strategies. Furthermore, shop-floor consumers are not the only audience for the activities of the sustainable seafood movement. Reputation with the general public who may or may not buy the products in question is important, and investors and regulators are also targeted in these performances. The purpose of this paper is to argue that the logic driving the sustainable seafood movement is best characterised as a "governance concert" with the audience made up of various stakeholders, including consumers as one important group.

The governance concert idea comes from governance and consumer research. Rather than seeing governance arising from one particular group of actors, such as government, the market, or in this case consumers, governance arises from diverse actors interacting in "concert" [35].

Sywngedouw's "choreographies of governance" illustrates this, explaining the emergence of governance innovation and the shift from either state-led or market-led governance, toward new combinations of "hierarchically nested and relationally articulated" actor networks [5,36]. Existing research into ecolabels and green consumerism lends support to the idea that comprehensive understanding of sustainability movements comes through viewing them as concerts made up of diverse actors working synergistically, rather than as being driven by one type of actor in isolation [37]. Ahir Gopaldas [38] conceptualises the retail space as a theatre for the performances of activists, retailers and brands to consumers, with activists aiming to recruit consumers to their cause and discipline suppliers, brands aiming to promote themselves, and consumers learning and communicating about products as part of their cultural lives. Echoing this, Gulbrandsen [33] finds that cases of fishery and forestry labelling indicate that the interactions of social movement organizations, states, consumers and companies explain the rise of labelling markets.

This paper arose through reflections on our previous empirical work on the tuna industry [5,16,39–43]. We became aware of the lack of analysis on the role of consumers in work on market-led approaches for sustainability. As noted above, research on the sustainable seafood movement tends to (a) assume consumer choice is a driver; (b) find that consumer demand is weak; or (c) find that it is the interaction between NGOs and retailers and brands that drives the movement. In each case, the role of consumers as governance actors is not critically examined.

The argument in this paper is based on insights from our previous empirical work along with a qualitative literature review. The literature search was conducted in July–September 2015 and June–August 2016 using databases via Google Scholar, Academic Search Complete (EBSCO) and SCOPUS (Elsevier). We first used terms to elicit articles on consumer behaviour regarding sustainability (such as ecolabel, green and ethical consumerism, sustainability marketing, food sustainability campaigns, consumer facing traceability, ecological modernisation). We then expanded the search to include terms that arose as relevant in some of the different discipline areas addressing the topic (audience, green/sustainable supply chain management, private governance, interactive governance, value chain). We also narrowed each search by combining terms specific to marine resource management (seafood, fisheries, fish, overfishing, aquaculture), but this restriction reduced the pool of literature too far so we included papers not about seafood. We found useful insights in the fields of marketing and advertising, public communication, consumer research, social marketing, green supply chain management, cultural studies of consumerism, and the political economy of private governance, as well as marine resource management.

The initial searching process raised hundreds of articles. By going through titles and abstracts, we excluded those that did not address the drivers for sustainability movements, leaving 192 articles. We read these and narrowed the pool further to 135 articles that illuminated existing research frameworks for understanding the drivers for sustainability movements. The literature was organised using EndNote software, with points from each piece relevant to our research questions included in the entries, producing a large annotated bibliography that could be searched, enabling us to distinguish themes among the articles. Qualitative analysis of the literature material followed an inductive process, as is usual in qualitative research [44]. We identified themes from the literature annotations that addressed and explained the research questions. We triangulated these themes against findings in our empirical work on the tuna industry, "grey literature" reports, media articles and web page statements by relevant organizations.

2. Whose Choice: Consumer or Retailer?

We commence consideration of consumers as part of the governance concert through the increasing tendency to shift the choice between products based on their ethical qualities from the supermarket shelf to retailers' procurement departments. "Sustainability"—which may be indicated by third-party certification or other methods—then becomes part of the procurement policy of the retailer, which requires suppliers to meet certain criteria to be able to sell to their products. At first glance, this trend is merely evidence that retailers rather than consumers are actively driving sustainability movements, but the trend is also useful for thinking through the role of consumers.

First, some of the rationales for retailers taking the role of checking the sustainability credentials of products on behalf of consumers illuminate the high level of complexity inherent in ethical consumerism in the form of individual shopper choices. A key point about the notion of having consumers choose between items based on their ethical qualities is that there is too much information for consumers to process. Even with just seafood, there are several labels, and there are various wallet guides, and for canned tuna there is an online ranking system, all of which give (sometimes conflicting) information about which types of seafood are more or less ethical to purchase [45,46]. Learning the systems behind each evaluation system and choosing among them is a significant task for even one type of product, and shoppers are expected to do it for every item in the supermarket basket. It is unrealistic to expect consumers to do this thoroughly and systematically [31].

Another important factor is the complexity of consumer ethicality itself. With the most recent wave of ethical consumerism starting in the late twentieth century, market researchers have been trying to work out how consumers who are susceptible to ethical marketing shop. They found the ethical consumer to be an elusive subject and attempts to type shoppers in terms of personality and demographics to predict their commitment to environmental conservation in shopping behaviour have not been very successful [30,47]. The reasons for the inability to identify shoppers who will reliably buy products marketed as green include: (a) there is large variation between types of green consumers; (b) social and environmental ethics do not always trump other values such as quality and price; (c) some green consumers are more committed than others; (d) different types of green consumers respond to different sources of information about the ethicality of products; (e) people may have an ethical concern for one product type but not others; and (f) consumers' ethics regarding shopping may change over their lifetime [21,30,48].

Moreover, another strand of research on "everyday ethicality" shows that concern for the environment is only one among several ethical issues at play behind consumption choices. Qualitative investigations into the ethics of shopping have revealed that rather than some consumers having ethical concerns and others not, in addition to the environmental and social conditions of production concerns more commonly thought of for ethical consumption, shopping always has ethical dimensions, such as caring for one's family, demonstrating thrift, even asserting national identity and political values [47,49–51]. Two consumers making polar opposite choices about what to buy may both have an ethical framework underpinning their choice [51]. Multiple ethics interact in individual purchase decisions, so the choices between ethical paths are often too complex to show up as a coherent pattern of behaviour in favour of any one ethic [30,49]. For example, a desire to support (imported) fair trade products may be derailed by ethics regarding food miles or localism, health concerns may lead shoppers away from some products with social or environmental responsibility qualities. The higher cost of products labelled as socially and environmentally responsible conflicts with a thrift ethic. A fair trade organic cotton shirt is incompatible with reducing one's ecological footprint by buying less [38,47,50]. Survey and interview research with consumers on their values around seafood in the USA found that in addition to sustainability, other concerns consumers have while purchasing seafood include price, nutritional value, and concerns about antibiotics and other additives [29]. Recognising this, some studies evaluate willingness to pay for several different kinds of ethical benefit in fisheries, including labour conditions as well as environmentally sustainable practices [52,53].

Both of these complexities—the amounts of information needed to decide between products on even a single factor such as "sustainability", plus the multiple ethical claims, along with aesthetic/quality and price values competing in shoppers' minds—can mean that ethical shopping is overwhelming rather than empowering. A shopper who trusts certain labels, such as Fair Trade, can thus be helped by those labels, at least in terms of being relieved of the work of finding out the ethicality of products. However, not all shoppers believe the claims behind the labels, and some indeed see ethical branding as just cynical marketing [47]. Even with ecolabels, consumers still need to weigh up between products, and that decision-making must be repeated for each item in the shopping basket. In light of all this complexity, a movement driven by consumer choice seems improbable.

Some of the literature on the shift to having retailer procurement systems do the research on products and make the decision for consumers couches the shift in terms of managing this complexity [31,48]. The idea is that shoppers choose a retail outlet whose overall "feel" lines up with their multiple values, including sustainability, trusting the retailer to have worked out the details and only put products that are ethically acceptable to their customers on the shelf. The shift to back-of-house for decision-making may thus simplify some of the complexity of consumers' multiple values in shopping, but the complexity of information required to determine the ethicality of products then falls on procurement managers. Supermarkets sell hundreds of different types of products and procurement managers cannot become experts in the methods of production for all of them; so intermediary bodies arise to help procurement managers select products that will meet their sustainability criteria. Ecolabels are one way to do this. When large retailers such as Walmart or the UK chain Sainsbury's commit to sourcing from MSC certified fisheries, they are effectively using the label as a procurement criterion.

There are also other methods for assisting procurement managers make more sustainable choices. The Global Sustainable Seafood Initiative (GSSI) is a tool being developed to enable seafood retail businesses compare between the array of different seafood sustainability certification systems. The Sustainable Fisheries Partnership (SFP) enables procurement managers to find out the sustainability status of whichever fishery they are thinking of buying from and thus implement a sustainable procurement policy without detailed technical knowledge of fisheries and aquaculture systems [54]. WWF advises procurement managers on sustainability across Europe, Australia, North America, Japan, Indonesia, China, and South Africa, working with large retailers, seafood brands, and aquaculture producers [55].

The inherent complexity of consumer ethicality and the shift towards retail chains making ethical choices instead of consumers both demonstrate the point that the sustainable seafood movement cannot be usefully explained by research on consumers only. Consumers must be researched as part of the overall concert, which includes other performers interacting along the supply chain.

There are bodies of research that consider governance in terms of whole supply chains or networks of actors and the interactions between different actors; Global Commodity Chains, Global Value Chains, Global Production Networks, and Supply Chain Management [5,56]. Research on Private Governance also illuminates interactions between different types of actors (for example, [57,58]). For example, ecolabels are apparently private arrangements involving voluntary standards, but in many cases states are also involved [59,60]. The "reconfiguration" approach to the field of Sustainable Consumption and Production, and third generation Ecological Modernisation approaches consider sustainability questions in terms of systems, in which both the individual choices of consumers and firms, and the overarching structures of industrial capitalism are key to improving sustainability [37,61]. The Interactive Governance approach in fisheries specifically looks at interactions between multiple diverse actors, mainly focused on the fishing node of the chain [62], but in some cases looking at whole supply chains [63].

Some of the insights gained from these approaches that consider governance as arising from the interaction among actors include the following: (a) power relations are key to the capacity of players to drive sustainability initiatives [57,64,65]; (b) the alignment of business interests along the supply chain enables sustainability initiatives while misalignment obstructs [31,43,66]; (c) ecolabelling has had the effect of disadvantaging smaller producers, especially the poor in the global South [6,67–69]; (d) evaluating the effectiveness of corporate social responsibility (CSR) activities is an important new research frontier [56,68,70]; and (e) ecolabels alone are not enough to address the sustainability challenges brought about by global industrial production [71]. Notwithstanding the value of these insights, none of these bodies of work address our questions about the role of consumers in sustainability movements. To further develop knowledge about sustainability movements as a governance concert, further attention must also be paid to the role of consumers.

3. Audience in the Governance Concert

In the contemporary business world, it is crucial for companies to be seen as “doing the right thing”, and conversely avoid being seen as “doing the wrong thing”. Initiatives such as ecolabelling may be seen as a performance of “greenness” on the part of retailers and brands. We argue that the main role of consumers has been as an audience in the sustainable seafood movement governance concert. Understanding consumers as an audience who think and feel things about companies more accurately conceptualises their role in the sustainable seafood movement, rather than as purchasers who directly financially incentivise the use of ecolabels.

3.1. The Aims of CSR

Conventional research on the sustainable seafood movement focusing on consumer choices to buy particular seafood products is concerned with one type of communication—marketing. However, concern about increasing revenue through selling specific products is only a narrow part of why firms engage in CSR initiatives. Sustainability and broader CSR initiatives are associated with communication strategies that go beyond getting consumers to buy or pay more for particular products. CSR activities are often about building and protecting corporate reputation [72], including building trust and “social license to operate” [73]. Studies about ecolabeling in forestry and other sectors note that ecolabels do not generate a clear incentive for ecolabeling through price premiums, echoing findings in seafood. In many cases, ecolabels are treated as a way to build and protect reputation with credible third-party information about social responsibility rather than as a way to directly increase revenue [26,31,33].

Some ENGO campaigns are key to this situation, through having drawn public attention to problems with overfishing or bycatch, and “named and shamed” some companies as sourcing unsustainably. One study of ecolabeling in forestry concluded that companies using the labels were not so concerned with whether the label caused consumers to choose some products over others, they were more concerned to demonstrate to consumers that their company was not part of the problem being highlighted by ENGOs [33]. Why might profit-seeking companies be more concerned with whether consumers see them as socially responsible than with the revenue they earn directly from the sales of ecolabeled products? Part of the answer here lies in brand value.

Companies engage in sustainability initiatives as a way to build the symbolic value of their brand through advertising and other marketing activities. In some cases, they do this even knowing it will not generate more sales or higher prices for the products being promoted. Their aim is to accrue value at a higher level in the company, for example, through share prices traded on financial markets [74]. Consumers play an important role here, as audience to the branding performance. The messages of sustainability initiatives become part of consumer culture. This form of communication has become key to management as well as marketing, because public opinion, involving feelings and thoughts about companies, has grown to be a central part of shareholder-facing corporate governance [75].

Environmental and social concerns are thus central to many retailers’ advertisements, and public relations campaigns, used to portray the company as a responsible corporate citizen [67]. One study of pricing in seafood ecolabelling gives an overview of the communication strategies that may be at play in retailers’ use of ecolabelling: retailers may be using ecolabels to differentiate themselves from other retailers; they may use them to imply that all products in the store are similarly sustainable; they may use them as loss leaders as part of a broader profit maximization strategy to bring consumers into stores; and they may form part of a broader corporate responsibility campaign to project a positive corporate image [26]. For example, Walmart and McDonalds have several times pledged that all their wild-caught seafood products will be MSC labelled, and in 2015 Ikea made a similar claim [76–78].

These claims have a high media profile, and since seafood is a small part of these companies' overall business, that is a lot of branding for a relatively small procurement change.

In addition to positive effects on branding, mitigating reputational risk is a related driver for sustainability initiatives like ecolabelling [79] and has been identified as a key driver behind the sustainable seafood movement [80–82]. As with brand value, the financial effects of loss of reputation may not be felt specifically in particular product lines, but may be more diffused throughout a retailer business. Costs may occur through stigmatisation, market resistance to environmentally harmful products, and it may occur through public and regulatory hostility towards organisations perceived as damaging the environment [83].

Performing greenness is one way to court consumers, and/or prevent a backlash from a perceived lack of greenness, providing consumers as a mass with considerable power. This power, however, is not being directly wielded by consumers through the conventional logic of "voting with the wallet", nor by consumer groups agitating for more sustainable sourcing through negotiations with seafood companies, media campaigns or participating in fisheries management meetings. These roles are being taken up by conservation groups [5]. Interviews conducted by the authors with procurement managers in seafood brand and trading companies across Europe, Australia and Japan revealed the operation of this power. For example, during fieldwork in 2011, Kate Barclay interviewed seafood managers in several Japanese seafood trading companies, who said until the early 2000s they would not normally meet with conservation groups. Since then, however, it became important to know what ENGOs were thinking about sustainability in seafood because their campaigns had become a major influence on consumer perceptions, particularly in European and North American markets. The managers thus started meeting regularly with international conservation group representatives.

3.2. Creating Receptive Audiences

Several countries with large seafood markets now have a situation where greenness is an important part of corporate image and where conservation groups are key actors in setting the agenda for public perceptions of companies, due to years of groundwork ENGOs have put into building awareness of sustainability problems in production. The sustainable seafood movement can thus be seen as part of a cultural shift towards more environmentally responsible behavior through building awareness of problems associated with fishing and the responsibility of all supply chain actors, including consumers, in supporting better practices. Social marketing researchers have found that altruistic, "biospheric" behavior towards environmental responsibility can be increased when the saliency of those values is strengthened relative to egoistic values affecting just the consumer themselves (such as nutrition, taste and price) via awareness raising activities [84]. This means raising the profile of environmentally responsible consumerism can contribute towards increasing environmentally responsible behavior. Ecolabels can therefore contribute to improving sustainability even when they are not associated with price premiums or increased market share, by sensitising consumers about their actions [85]. Indeed, even when sustainability initiatives may be accurately described as "greenwash", in that they are not demonstrably directly improving the sustainability of production and seem to be mainly aimed at improving brand reputation, such initiatives can further the aims of the sustainability movement as a form of social marketing [38]. When ubiquitous brands make commitments around seafood sustainability (e.g., large brands' commitments to dolphin safe tuna, or mega-retailers like Walmart committing to MSC certified seafood), the sentiments of ethical consumerism are disseminated to vast numbers of mainstream consumers. Therefore, to be more effective, efforts to improve ocean sustainability must go beyond narrow quantitative research examining direct causal relationships between certification and sales of certified products and/or stocks of certified fisheries, to consider more diffuse processes of normative change and its effects on behavior, in which precise measurement and attribution are difficult [86].

The use of marketing to spread acceptance for social messages requires pre-existing cultural knowledge to be in place [87]. This includes broader cultural trends as well as context specific to the social message. Information campaigns generate cultural knowledge that there are sustainability problems with the production of consumer goods, central to social marketing [88] and behavioral economics [89] approaches aiming to motivate people to buy greener options. The creation of receptive audiences is a key point for thinking about the conditions under which the sustainable seafood movement can significantly impact fishing practices.

Europe- and North America-based ENGOs started concerted campaigning on overfishing in the 2000s. This included targeted actions at seafood trade shows [90] and sustainable seafood wallet guides and smartphone apps for consumers [46]. For canned tuna, the online Greenpeace canned tuna rankings implemented in several countries have boosted awareness of overfishing associated with certain methods of fishing (see for example, [91]). The efforts of ENGOs have dovetailed with activities by scientists and the media in building public awareness that overfishing is a problem. Examples include much of the work by scientist Daniel Pauly; well-publicised papers on overfishing [92]; investigative journalism into illegal fishing and trading of northern Bluefin tuna from the Mediterranean to Japanese markets [93]; the film *The End of the Line* [94]; and the British television program *Hugh's Fish Fight*, which then turned into an ongoing campaign [95]. The general public may not have a detailed or accurate understanding of the intricacies of sustainability issues in seafood production, but now most people exposed to this media and these campaigns are aware that overfishing is a problem, and thus performances of greenness have become a necessary part of business in the seafood retail industry.

Some of the media campaigns indeed have encouraged consumers to engage actively with retailers, not only in buying more sustainable options, but in asking retailers about the sustainability credentials of their seafood offerings [96]. If the retailer is unable to give a satisfactory answer, consumers may express dissatisfaction and refuse to purchase in front of other customers. These kinds of campaigns complement seafood species pocket guides and/or smartphone apps taking the sustainable seafood movement into the food service sector, whereas ecolabels and rankings of canned tuna are more limited to supermarket outlets. The food service sector constitutes a significant market channel, so if the sustainable seafood movement is to affect production practices it must operate also in the food service sector. Some restaurants use seafood sustainability in their branding [97]. Other types of institution also tap into the sustainable seafood movement to bolster their green credentials, including universities [98], and zoos [99].

The fore-mentioned media and scientific papers have largely been in English language, and until recently ENGO campaigns have mainly been conducted in Europe, North America, Australia, South Africa, New Zealand and so on. Broad public awareness of overfishing as a problem within the seafood consumption sphere (as opposed to the fishing sphere) is much lower in other key seafood market countries. Researchers have pointed out that ecolabelling has been less prevalent in Asian seafood markets than in Europe and North America [45]. People in and around fishing communities across the world are aware of the problems caused by overfishing, coastal development and climate change. The idea that seafood consumers and retailers are, in part, responsible for fixing this problem with their purchasing choices, however, has arisen from the sustainable seafood movement and is less prevalent in parts of the world where the sustainable seafood movement has not yet been promoted actively or effectively. For example, in a recent interview study of Chinese seafood importers, most respondents felt that addressing overfishing was the responsibility of fishing state governments, and not the responsibility of market actors [100]. Traders in that study were asked whether ecolabeling or other market initiatives would be useful for the sea cucumber trade and nearly all responded negatively, saying that they saw no market advantages. In recent years, there have been anti-shark fin consumption campaigns in China so there is some public awareness of overfishing for sharks, but this is not the case for other overfished species such as sea cucumbers [101]. Multinational research indicates that there are no clear delineations regarding the propensity for ethical consumerism between cultural groups (or gender or class) [21]. The significance of ecolabels in particular markets is dynamic, with ecolabels for canned tuna becoming important in new markets where previously they have not been [102]. Studies in China and Japan have found when people were given information about overfishing before undertaking willingness-to-pay surveys, they showed more positive responses to ecolabels than people who were not given this information [103,104]. Spreading the message that seafood consumption patterns are part of the problem of overfishing is a precondition for the sustainable seafood movement to take root in new markets.

Underlying cultural landscapes mean that messages about sustainability must be framed appropriately in order to gain traction. Market researchers surmise that organisations such as MSC have had little success in Japan because MSC's established strategies were developed in the contexts of Europe and North America. Greater take-up of ecolabels in Japan would require tapping into local conditions, such as the strong food localism movement in that country [105]. The strong role of the state in mainland China and the high profile of food safety should be taken into account in developing sustainable seafood campaigns in China [17]. ENGOs have started campaigning in China in recent years, but using strategies designed and tested in Europe and North America, which has given rise to messages that are not effective in changing behavior among Chinese audiences [106].

The success of a Greenpeace campaign in Australia demonstrates the level of impact possible when the cultural knowledge of the audience is a good fit for the ENGO message. The Australian public has been primed with information about overfishing, and Greenpeace has established itself as an authoritative voice on sustainability regarding canned tuna with local canned tuna rankings since 2009. Furthermore, since the 1970s in Australia, the public discourse about environmental responsibility has been closely bound up with the protection of charismatic megafauna [107]. As part of the canned tuna rankings work, Greenpeace campaigners have been negotiating behind the scenes with brands and retailers to change their procurement policies. They had been unable to get John West in Australia to stop sourcing from fisheries using fish aggregating devices (FADs) that result in greater bycatch than fishing on free-swimming schools of tuna or using pole-and-line methods. John West had thus been ranked low but in 2012 Greenpeace took the campaign one step further, with a YouTube video, demonstrations outside retailers and billboard posters asserting that the fisheries from which John West Australia sourced tuna caused overfishing and the bloody deaths of turtles, sharks and rays [108]. Within three months of the launch of this campaign, John West Australia changed their procurement policy. According to the John West website, "following recent pro-active engagement with Greenpeace we have sought to clarify our current commitment to the sustainable sourcing of tuna" committing that by 2015 the company would no longer source FAD-associated purse seine-caught tuna [109]. This case exemplifies the way the sustainable seafood movement acts as a concert, with an ENGO and a brand both performing greenness to the consuming public as audience. No consumer groups were involved in the campaign. We do not know if the campaign affected sales of John West tuna or whether retailers also put pressure on John West to make the scandal go away, but clearly the general public, including consumers of John West products, were important as an audience. The Australian audience, in the 2010s, was one in which messages about killing turtles and overfishing were effective in influencing perceptions of the John West brand. Another audience at another time may not have been so receptive to the same messages.

The process of creating a receptive audience may be conceived of as developing the backdrop to the governance concert of the sustainable seafood movement. It is a necessary (but not sufficient) condition for the sustainable seafood movement to gain traction. Knowledge and values about overfishing as a problem, and norms that this problem should be addressed at the consumption node of the supply chain as well as the fishing node, become part of consumer culture. Consumer culture sits in the background, colouring perceptions of what kind of behaviour is (il)legitimate and thus influencing behaviour. The tacit knowledge of consumer culture is what renders the shorthand of an ecolabel legible, and is a determining factor in whether an audience is receptive to messages about ethical production and consumption. The process by which some audiences in Europe, North America and other countries have become receptive to the sustainable seafood movement is illustrated in Figure 3. The groups whose actions have most helped generate the sustainable seafood movement—ENGOs, scientists, the media—are surrounded by stronger colour, but all groups marinade in this new consumer culture. This does not mean all groups or subgroups come to have the same norms or behave in the same way, but it means all groups are aware of the idea that consumers are, in part, responsible for sustainability and can understand why something like an ecolabel might be considered as a solution. The route by which audiences become receptive may differ in different markets.

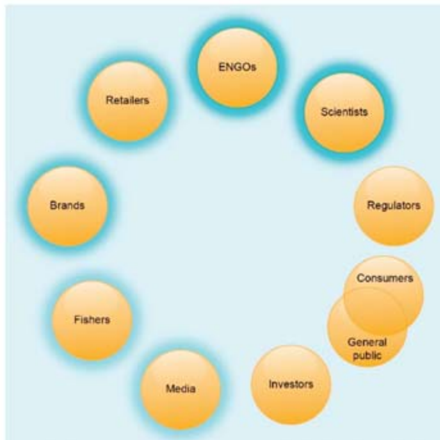

Figure 3. Creating a Receptive Audience for the Sustainable Seafood Movement.

It is not a simple thing to create an audience. The development of the Australian public as a receptive audience for the Greenpeace campaign took place over years for canned tuna specifically, decades if we include the charismatic megafauna aspect. Moreover, setting out to create an audience for a particular message and change behaviour in the desired direction does not always work as planned. Within marketing and communication studies, the field has evolved over the decades from a mechanistic view of audience as programmable through advertising, through to the other extreme of asserting that audiences can freely decide for themselves what to think and feel, back to somewhere in the middle [110]. Well-designed and resourced communication campaigns can have an effect on public opinion, while consumers also develop their own unpredictable ideas about products and industries [111]. Social marketing offers one way forward. Social marketing principles of campaign design, monitoring and evaluation are based on the idea that that success is due to sound understanding of the target audience(s). Much may be learned from social marketing analysis of audience for building strategies to improve sustainability in marine activities [112].

3.3. Non-Consumer Audiences

Consumers are the main focus of this paper, but when we look at consumers as audience in governance concert, it becomes clear that consumers are only one among several audiences. Some kinds of marketing address regulators and other actors who may be influenced by perceptions of the company as a corporate citizen. In addition to customers, regulators, ENGOs and peer companies in the sector are also important audiences for the sustainable seafood governance concert. Furthermore, the general public—including people who do not buy the products in question as well as direct consumers—is an important audience.

CSR initiatives often go beyond consumer-facing attempts to boost sales of a particular product, or even to build a whole brand, and are part of the field of 'strategic communication' that targets multiple audiences [113]. Consultants brought in to work with companies on CSR as part of a strategic communication plan may not meet with the sales department, but work with management to target multiple audiences to build brand and reputation for broad purposes including government relations and investor relations [113]. The rationale for this kind of communication is that if a company is seen as "doing the right thing", it is more likely to be treated leniently by government in monitoring and if breaches arise. Entire industries may work towards building their collective reputation as corporate citizens, so as to encourage government to let them self-regulate and avoid onerous government regulation [33,67]. In several developing countries, ecolabel certification has been found to improve government perceptions of the sustainability of fisheries, leading to favourable treatment [8], including regulatory leniency, improved resource access rights and provision of infrastructure [114].

Sustainability performances are also increasingly important to secure financial investment. One study points out that, in 2015, 1400 investors managing combined assets of USD59 trillion signed on to the United Nations Principles of Responsible Investment [115]. Companies are seen as performing against a triple bottom line by the public as well as investors and shareholders [56]. This is where the general public, beyond direct consumers per se, become an important audience. Investors that operate under government mandates, such as sovereign wealth funds and pension funds, may be required to meet ethical standards as well as achieve profits. Private investors also often have CSR criteria in their own corporate governance strategies, which may affect their investment decisions. In 2016, Walmart's two top institutional investors were Vangard and State Street [116]. Both of these investors have statements about CSR on their websites [117,118], so it is likely that investors are one audience for Walmart's sustainability initiatives. A superannuation investor withdrew from a large salmon-farming venture in Australia over concerns about the environmental sustainability of the company's practices [119]. Other kinds of investors for whom sustainability concerns are important include philanthropic organisations, charitable trusts and ENGOs investing in sustainable seafood work [105], including fishery improvement projects and government capacity development for policy and management advancement.

4. A New Logic for Understanding the Sustainable Seafood Movement

Earlier in the paper, we pointed out that the consumer-driven logic of ecolabels is empirically inaccurate, and that the ENGO-retailer/brand-driven logic is incomplete, because it leaves out the role played by consumers. Having critically examined the role of consumers in this paper, synthesising ideas from the literature review on consumers and other audiences for CSR and ecolabels as green performances with our understanding of the sustainable seafood movement as part of a governance concert, we have developed a new model for the sustainable seafood movement (Figure 4). The sustainable seafood movement constitutes a governance concert, with different players, including fishers and aquaculture producers, interacting to drive the story, a backdrop of cultural knowledge making the story legible to the audience, and multiple audiences, including consumers and the broader public (including non-consumers), but also regulators and investors (who are both in turn affected by perceptions held by the general public). When any of these actor groups participates in the sustainable seafood movement, they are performing to certain audiences. Conceptualising the sustainable seafood movement in this way reveals the importance of consumers. While consumers have hitherto not been active in driving the movement through voting with their wallets or through representative groups agitating for change, consumers are a very important audience group. According to our qualitative investigation, more actors in the sustainable seafood movement perform to consumers and the general public than to any other group (as shown by the arrows).

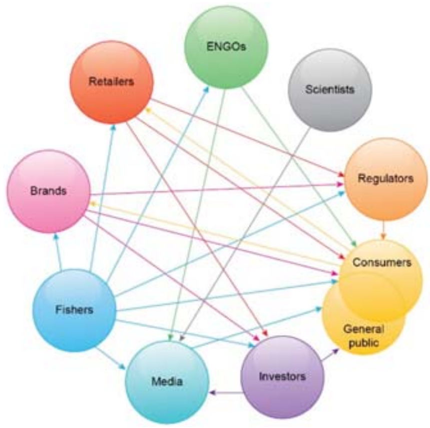

Figure 4. New logic: sustainable seafood as part of a governance concert.

As other researchers have pointed out, ecolabels alone are unlikely to achieve positive change in the sustainability of seafood production [8]. As part of a broader governance concert, however, they may contribute to positive change, for example, through influencing regulatory processes.

The emergence of the sustainable seafood governance concert has not been a smooth or fast process coordinated from a central point, nor does this governance concert manifest in the same form in different places. The cultural knowledge backdrop varies across time and place, with broader social trends affecting audience receptions of the concert. Fishers make a living from the shifting natural and social world, in which market opportunities such as ecolabel certification rise and potentially dissipate [119]. In Europe and North America where the sustainable seafood movement is now coherent enough to constitute an influence on market behaviours, it has emerged organically over two decades with changing dynamics between the different groups involved, not always in synergy. Shifting power dynamics between groups has been a major factor shaping the sustainable seafood movement [12,120,121]. In other large markets in China and Japan where the sustainable seafood movement has not to date been a significant influence, it may yet become significant, but the precise composition of the concert will be path dependent, reflecting underlying differences in the social and market contexts, such as the pre-eminence of food safety concerns in both countries and the well-established cachet of food localism in Japan.

5. Conclusions

In this paper, we have argued that previous research on the sustainable seafood movement has been too narrowly focused on consumers' actual and reported willingness-to-pay for sustainable seafood, and price incentives for certified sustainable seafood. To properly understand why the sustainable seafood movement continues to grow despite weak consumer demand and weak or non-existent price incentives to participate in sustainability initiatives, we need to look beyond single actor groups, such as consumers, and consider consumers acting in concert with other types of actor along the supply chain. From this perspective, audiences, including consumers, constitute a strong reason for participating in sustainability initiatives, even when prices and sales of the product in question are not positively affected by the initiatives. The ecolabel is "working" just by having consumers see it on the shelf, even if they then skim over it to buy a cheaper option. Considering ecolabels as one part of broader communication strategies employed by brands and retailers shows how ecolabels can be fulfilling their aims in communicating to consumers even when consumers do not buy the products or do not pay a premium that covers their greater production costs.

Research into the sustainable seafood movement as a governance concert should thus go beyond the conventional questions—whether consumers are buying sustainable options and the prices they are willing to pay—to understanding consumers (and non-consumers) as audience to the sustainability performances of companies they buy from. In this role, consumers contribute to making retailers and brands buy more sustainable options, and fishers to shift to more sustainable methods. Furthermore, research on the sustainable seafood concert should aim to improve our understanding of the quality and quantity of CSR initiatives in actually improving fishing practices (socially, economically and biologically), for which marketing research design and monitoring and evaluation frameworks constitute a useful direction [113]. A research frontier exists in evaluating what companies are trying to achieve with their sustainable seafood initiatives beyond sales of specific products and the potential impact of these drivers on sustainability in production, or even all the way along the supply chain. Research on audience in the sustainable seafood governance concert could address questions such as why Australian retailers stock a token amount of ecolabeled canned tuna, whereas large retail chains in Europe and North America aim to stock only ecolabeled tuna [68]. Is this difference due to internal values of the companies involved, consumer audiences in the respective markets, the regulatory environments, the concerns of investors for each company, or a combination of the above? How does that vary in the large markets of Japan and China? Noting that these situations change, sometimes quickly, what factors in which markets are decisive in high quality, large magnitude shifts towards sustainability?

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Flame Retardant Contamination and Seafood Sustainability

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Abstract: A growing body of evidence for chemical contamination in seafood has raised concerns about the safety of seafood consumption. Available data also indicate that some fishery stocks that are overharvested are also the most laden with certain contaminants. Flame retardant chemicals, used in textiles, plastics, and other products are a class of these seafood contaminants that are particularly concerning as they are linked to cancer and endocrine disruption. To investigate the potentially useful relationship between fishery sustainability and flame retardant concentration in seafood, we used polybrominated diphenyl ethers (PBDEs) as a case study to assess how fishery status and species vulnerability coincide with levels of brominated flame retardants found in the tissue of popularly consumed fish. While none of our metrics of sustainability showed strong relationships to PBDE contamination rates, our results suggest that the same intrinsic biological and ecological traits, which facilitate the uptake of chemicals, also contribute to how species respond to fishing pressures. Given the dual challenges of ensuring seafood sustainability and protecting human health, we then explored the implications of bundling the public good of conservation with the private good of health.

Keywords: contamination; fish; fisheries; flame retardants; health; PBDE; seafood; trophic level

1. Introduction

Historic management of economically and ecologically valuable species has placed many fisheries around the world in danger of decline or collapse. This decline brings significant long-term consequences for global biodiversity, and affects hundreds of millions of people who rely on fisheries as a primary food source [1–3]. Despite motivation to confront this problem, fishery scientists struggle with how best to address fishery collapse [1,4]. Human health depends on the sustainability of seafood in ways beyond subsistence alone, as seafood can be a healthy dietary choice due to its high nutrient content, including selenium and long-chain omega-3 acids [5–8]. Even with the well-documented benefits of seafood consumption, there is growing evidence showing serious health risks due to chemical and heavy metal contamination of seafood from the accumulation of xenobiotic substances (contaminants) ingested or absorbed by the fish via their environment prior to harvest [7].

The prevalence of mercury and methylmercury in seafood has received much attention in recent years due to its significant health effects, especially on the cognitive capabilities of young children [8]. While mercury has been the most commonly discussed contaminant found in popularly consumed fish species, a different class of contaminants has begun to cause concern among medical and environmental researchers. Flame retardants, particularly brominated flame retardants, are used in products such as textiles, furniture, electronics, plastics, and other building materials to decrease the chance of combustion and reduce fire danger [9–13]. Though humans are exposed to flame retardants through dust released from common household items, most of these persistent organic pollutants (POPs) found in human bodies come from the consumption of fish and shellfish—even when seafood is a small part of the diet [14]. These, and other POPs, are referred to as persistent because they do not readily break down in the environment. While there is uncertainty about the exact long-term effects of flame retardants on human health, these chemicals are known to disrupt endocrine function, impair spermatogenesis, interfere with neurodevelopment, and act as carcinogens. Despite this, flame retardants are produced and distributed under the auspices of human safety and are already pervasive in the environment [12,15,16]. PBDEs (polybrominated diphenyl ethers) are a class of commonly used brominated flame retardant which, like mercury, biomagnify in the food chain. Concentrations of such substances amplify as they are passed up the food chain. The top predator (often humans) consumes the highest concentrations of the substances, which the body is unable to break down or digest. When PBDE does metabolize in the environment, the molecule can break down into new brominated compounds, such as hydroxylated polybrominated diphenyl ether (OH-PBDE) or methoxylated polybrominated diphenyl ether (MeO-PBDE). These compounds are still toxic. For these reasons, certain congeners of PBDEs have been banned by the European Union.

Previous research suggests that ecologically sustainable seafood, in general, contains less mercury, revealing a common ground shared by the proponents of both human health and conservation [17]. In principle, pressures on many overfished stocks could be lessened by demonstrating to consumers and industry leaders that many threatened fish stocks also tend to be unhealthy in the human diet so that reducing consumption of these less-healthy species on the basis of the 'private good' of human health may pay a double dividend to the 'public good' of fishery sustainability. In this paper, we seek to examine the generality of the relationship between contamination and sustainability in the case of flame retardants. Specifically, we examine PBDE concentrations reported in commercial fishes and linked each data point to corresponding metrics of sustainability. We also consider the association between PBDE concentrations and biological predictors of fishery sustainability. Given the dual challenges of ensuring seafood sustainability and protecting seafood consumers from excessive PBDE exposure, we then discuss the potential for sustainability and health messaging to consumers (e.g., seafood advisories or press releases).

2. Materials and Methods

We collected globally-recorded concentrations from the published literature of PBDEs for consumed species of fish or shellfish from both marine and freshwater sources. All samples were collected between 2002 and 2012. The dataset included 458 samples containing 187 types of fish from 41 contributing sources and 49 unique PBDE congeners, or specific chemical varieties. Some researchers analyzed for individual congener concentrations, while others reported the sum of total PBDEs. This means two authors might report ΣPBDE, for example, but one author analyzed for PBDE, in general, and the other for specific congeners, such as BDE-47, BDE-99, and BDE-152, and added the results for reporting. We utilized only those values ($n = 328$) which were reported as ΣPBDE to maintain as much consistency as possible across different labs which likely tested for varying sets of individual PBDE congeners.

To put the values displayed in this article into context, the Agency for Toxic Substances and Disease Registry (ATSDR) provides a Minimal Risk Level (MRL) for decaBDE and lower brominated BDEs. The MRLs for oral exposure to PBDEs provide a threshold "at or below which that substance is unlikely to pose a measurable risk of harmful (adverse), noncancerous effects ... however ... MRLs should not be used as predictors of harmful (adverse) health effects" [18]. Cancer, however, though notoriously difficult to research and trace back to a point source, is a central concern when considering brominated flame retarding chemical additives. The MRL for decaBDE is 10 mg of PBDE per kg of body weight, per day, determined by oral exposure spanning 15–364 days. The MRL observed over the same timeline for lower brominated BDEs is 0.007 mg/kg/day. Assuming the average adult weighs

70 kg, the ATSDR states that a person is unlikely to experience adverse health effects unless he or she consumes more than 7.0 × 10^8 ng of decaBDE per day or 4.9 × 10^5 ng of lower brominated BDEs per day. These thresholds are several orders of magnitude higher than the amount of PBDEs the average American consumes via fish and shellfish (Figure 1). The PBDE concentration data portrayed in this figure come from 27 different published sources, including academic papers and government reports. Shrimp appear to be of special concern since it is both relatively high in PBDE content and is also consumed more frequently by the average American. Although the MRL range for PBDE is far higher than what the average American consumes on a yearly basis, PBDE is just one of many possible chemicals which are found in human bodies, the interactions of which may amplify toxic effects (Figure 2) [19].

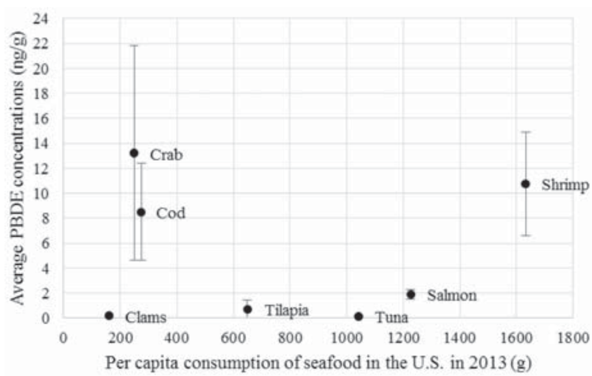

Figure 1. The risk of consuming popular seafood choices. Seafood types here reflect the average PBDE concentration of multiple species within that category. For example, "Cod" includes observations of Atlantic cod, Pacific cod, and Polar cod. Catfish, an outlier, was excluded (1008.33 ng/g ± 826.8, mean ± standard error).

We examined a number of other variables, apart from PBDE concentrations, which describe the types of fishes in the dataset. These variables can be assigned to one of two categories, pertaining to either sustainability or biological traits. Sustainability variables include (1) $B_{current}/B_{MSY}$ (current available biomass/biomass available if harvested at MSY); (2) $u_{current}/u_{MSY}$ (current harvest rate/harvest rate at MSY); (3) sustainable seafood guide rankings from the Monterey Bay Aquarium (MBA); and (4) vulnerability values published by Cheung, Pitcher, and Pauly [20]. $B_{current}/B_{MSY}$ and $u_{current}/u_{MSY}$ were both collected from Worm et al., calculated from information collected between 2001 and 2009 [1]. MSY, maximum sustainable yield, refers to the calculated level of harvest at which a natural resource can predictably be harvested without causing future depletion. Worm et al. use harvest rate to signify the fishing mortality rate [1]. In the second category, the biological variables are life history traits intrinsic to the species, and include depth, weight, lifespan, water zone or habitat, and trophic level. Fishbase.org and SeaLifebase.org provides these, including maximum reported depth, maximum reported weight, maximum reported age of a species of fish, zone, and trophic level, a value showing where a species is found in the transfer of energy of the food web. Zone refers to different layers of water, such as demersal, pelagic, or benthic.

$B_{current}/B_{MSY}$ and $u_{current}/u_{MSY}$ have been estimated and reflect the conditions of the current population (data recorded 2001–2009) compared to the conditions of the stock under specific management scenarios that are assumed to be sustainable [1]. From a single-species perspective, a biomass ratio ($B_{current}/B_{MSY}$) that is greater than 1 indicates better ecological sustainability, whereas a harvest ratio ($u_{current}/u_{MSY}$) that is less than 1 indicates better sustainability [1]. Vulnerability values [20] take inherent biological characteristics into account, such as reproductive history, lifespan, and resilience under stress, while public seafood guides, including the MBA [21], evaluate sustainability mainly by considering the environmental impact of current stock-specific harvesting techniques. Vulnerability rankings [20] are assigned on a scale of 0 to 100, with 100 being most vulnerable (and least sustainable, in context of this study), while the Monterey Bay Aquarium seafood guide provides a numerical value with two decimal places from 0 to 10, with 10 being the 'best choice'. MBA values are designed to reflect sustainability of specific fishing practices in specific locations. In order to disentangle the relationships between ecological sustainability, flame retardant concentration, and life history traits, we constructed a range of regression models to investigate three key relationships: (1) the relationship between PBDE concentrations and metrics of sustainability; (2) the links between PBDE concentrations of a species and its innate biological traits; and (3) the relationship between sustainability metrics and these biological life history variables (Table 1). We used the four variables as indices for sustainability ($B_{current}/B_{MSY}$, $u_{current}/u_{MSY}$, vulnerability, and MBA seafood guides rankings) from the most informative and robust regression scenarios possible given the size of the dataset. For biological life history traits we consider the species trophic level in the food chain, which can be a useful, but noisy, predictor of fishery sustainability. This is because many species at the top of the food chain exhibit vulnerable life history traits, such as increased longevity and body size, and lower reproductive rate, and may be harvested vigorously due to their often high market value [22]. Aquatic zone is also considered since flame retardants released into the environment are sourced from highly-populated human centers of both production and use, suggesting contaminant concentrations may be higher in fish populations located nearest to land.

The models in Table 1 were chosen because these combinations of covariates helped illuminate possible trends and how these trends fluctuate with varying sets of control variables, while also acknowledging the need to conserve statistical power given the limited degrees of freedom present in our data. For example, we did not include controls for region when focusing on the Worm et al. values, biomass and harvest rate, or on the MBA seafood guide values, because these indices are composed mainly of North American observations, and also because the sample size was small. In fitting linear models to variables in various tests, we employed a weighted least squares approach that weighs an observation, in the case of multiples of that fish type in the same region, by the inverse of the number of total observations of the fish type in the region. We utilize this approach to mitigate excessive influence in our estimates from highly studied regional fish stocks; these stocks may be more likely to be studied (or published) precisely due to concerns over potential contamination. Our approach hopes to limit the reach of this potential selection bias. To demonstrate: if multiple authors reported contamination levels in common carp from Southern Europe, we needed to reduce the influence each observation carried in the regression so the information would remain comparable to, for example, Northern European cod reported by only one source.

Table 1. Multivariate regression models chosen with respect to available data and sample size.

		Dependent Variable	Independent Variables
PBDE~Sustainability	Model 1	PBDE	MBA
	Model 2	PBDE	Vulnerability, Region
	Model 3	PBDE	Biomass
	Model 4	PBDE	Harvest rate
	Model 5	PBDE	Biomass, Harvest rate
	Model 6	PBDE	Vulnerability, Biomass, Harvest rate
PBDE~Biological metrics	Model 7	PBDE	Trophic level, Region
	Model 8	PBDE	Trophic level, Depth
	Model 9	PBDE	Trophic level, Depth, Region
	Model 10	PBDE	Trophic level, Depth, Zone, Region
	Model 11	PBDE	Trophic level, Depth, Zone, Weight, Lifespan, Region
	Model 12	PBDE	Trophic level, Depth, Zone, Weight, Lifespan, Length, Region
Sustainability~Biological metrics	Model 13	Biomass	Trophic level, Depth, Zone, Weight, Lifespan, Length, Region
	Model 14	Harvest rate	Trophic level, Depth, Zone, Weight, Lifespan, Length, Region
	Model 15	Vulnerability	Trophic level, Depth, Zone, Weight, Lifespan, Length, Region

In addition to multivariate regression modeling, we also utilize simple bivariate statistical estimates to explore the pairwise correlations between ecological sustainability, flame retardant concentration, and life history traits. We used a categorical approach to investigate these broad estimates, and assigned three categories to depth, weight, lifespan, zone, and trophic level. The cutoffs for these categories were established by choosing commonly-used classifications while also taking into account the sample size within each category. We ultimately chose boundaries for three categories so that each category has a roughly comparable sample sizes.

3. Results

Our analyses suggest a complex relationship between PBDE concentrations and seafood sustainability. At first glance, shallower analyses support our educated assumptions that PBDE concentrations correlate to species characteristics which facilitate uptake of chemicals (Figure 2). Trophic level displays a broadly indirect relationship with PBDE (Figure 2). These results concerning the trophic level were in contrast to what we originally hypothesized based on our knowledge of market drivers, as we assumed many large and long-lived species are found at higher trophic levels.

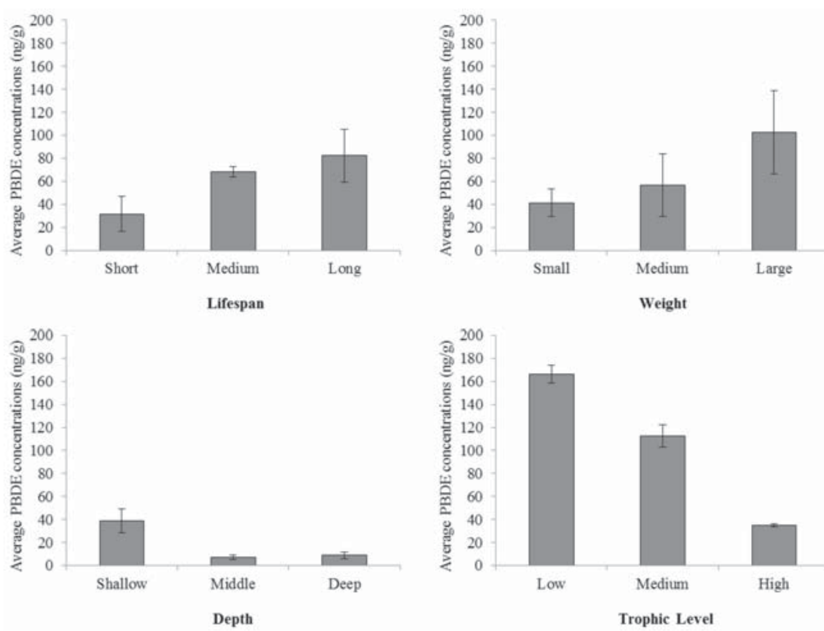

Figure 2. PBDE concentrations and biological characteristics. Depth refers to the maximum recorded depth a fish of that species was caught at historically; Weight, the maximum weight; and Lifespan, the oldest recorded age (mean ± SE).

We then further explored the statistical power within the relationships between PBDE concentrations, sustainability metrics, and life history traits, revealing complications and less clear conclusions (Tables 2–4). Table 2 addresses the first of our hypotheses, that sustainability quantifiers may correctly predict PBDE concentration levels. None of the four measures of sustainability (biomass ratio $B_{current}/B_{MSY}$, harvest rate ratio $u_{current}/u_{MSY}$, vulnerability, and MBA seafood guide values) showed strong relationships to PBDE contamination rates found in seafood sampled between 2002 and 2013 (Table 2). While Models 1, 4, and 6 include sustainability variables bearing significant *p*-values, the sample sizes available to each of these regression models are unreliably small.

Table 2. Examining sustainability metrics as predictors of PBDE concentration in seafood. Estimates (*t*-statistic), with significance indicated by † for $0.05 < p < 0.1$, * for $0.01 < p < 0.05$, ** for $0.001 < p < 0.01$, and *** for $0 < p < 0.001$.

Independent	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
MBA Guide	0.8545 (4.359) ***					
Vulnerability		−0.0054 (−0.700)				0.0084 (0.195)
Biomass			−0.1810 (−0.160)		0.3282 (0.291)	−1.1600 (−2.096) *
Harvest rate				3.300 (2.900) **	2.4119 (1.908) †	0.4020 (0.543)
Number of observations	22	333	28	28	28	28
Region (dummy)		X				
R-squared	0.4872	0.2902	0.0011	0.2518	0.1432	0.2317

In our analyses of the relationships between PBDE and sustainability, we were limited by data availability (small sample size) and low R-squared values (Table 2). However, the practical relationships between the variables discussed here (sustainability, PBDEs in fish tissue, and species differences) suggest that PBDE concentrations are influenced by spatial and biological characteristics of regional stocks, if not by ecological sustainability. We show this broadly in Figure 2 and now delve further into the statistical power behind these relationships in Table 3.

Table 3 supports the idea that larger fish require more energy for survival (i.e., more prey) and, therefore, will show more biomagnification of contaminants, and longer-lived species have more time to accumulate chemicals (Model 12, R-squared = 0.7617). Further, larger and longer-lived species are often found at higher trophic levels, as exemplified by tuna and other sportfish. The influence of trophic level as illuminated by the regression scenarios here are not as simple as that, however. After controlling for region of capture, we found a strong negative relationship between trophic level and PBDE contamination ($p = 1.63 \times 10^{-6}$; Table 3). Although we might have expected lower trophic level species such as shrimp or mussels to have relatively lower contaminant levels due to biomagnification of flame retardants, this result to the contrary may be explained by the fact that such species spend much, or all, of their time at the bottom in the sediment near land. PBDEs generally enter the aquatic environment via runoff from land, and can accumulate in coastal sediments [23]. Where external variables such as increased exposure to sediment may interfere with trophic level-based predictions of contamination, the results more definitively show that larger and longer-lived species have potentially greater capacity for contamination accumulation (Model 12).

Table 3. Examining biological characteristics as predictors of PBDE concentration. Estimates (*t*-statistic), with significance indicated by * for $0.01 < p < 0.05$, ** for $0.001 < p < 0.01$, and *** for $0 < p < 0.001$. For categorical variables (Zone, Interactions), the coefficient with the highest *t* value was chosen for display in the table.

Independent	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
Trophic level	−1.1764 (−4.922) ***	−1.5492 (−6.321) ***	−1.7205 (−6.800) ***	−1.2792 (−4.209) ***	−0.7710 (−1.417)	−21.21 (−0.822)
Depth		0.0002 (0.357)	0.0003 (0.622)	0.0003 (0.391)	−0.0002 (−0.092)	0.0069 (0.043)
Zone (dummy)				Pelagic-oceanic −2.6064 (−0.938)	Bentho-pelagic 3.1754 (2.564) *	Pelagic-oceanic 4.849 (0.628)
DepthXZone				Demersal −0.0009 (−0.711)	Demersal −0.0014 (−0.682)	

Table 3. *Cont.*

Independent	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
Weight					−0.0063 (−1.453)	0.0168 (0.009)
Lifespan					0.0125 (0.597)	−3.956 (−1.358)
Length						0.1837 (0.192)
Number of observations	239	170	170	161	83	83
Region (dummy)	X		X	X	X	X
R-squared	0.2283	0.1997	0.3237	0.4767	0.4612	0.7617

Finally, we found intrinsic biological traits of fishes to have the most influence on quantified sustainability (Table 4). Although sample size is limited by availability of sustainability metrics, multiple R-squared values are high when all biological traits and trophic level are considered. Life history traits represent an indirect link between sustainability and PBDE contamination, predicting both sustainability and PBDE concentrations.

Table 4. Examining biological characteristics as predictors of sustainability. Estimates (t-statistic), with significance indicated by † for $0.05 < p < 0.1$, * for $0.01 < p < 0.05$, ** for $0.001 < p < 0.01$, and *** for $0 < p < 0.001$. For variables which included multiple estimates (Zone), the coefficient with the highest *t* value was chosen for display in the table. Fish length is omitted from Model 15 to retain sample size.

Independent	Model 13 (Dependent: Biomass)	Model 14 (Dep: Harvest Rate)	Model 15 (Dep: Vulnerability)
Trophic level	28.07 (1.743)	−20.14 (−1.073)	−13850 (−2.714) *
Depth	-5.49×10^{-5} (−0.061)	−0.0006 (−0.535)	−70.03 (−2.744) **
Zone (dummy)	Pelagic-oceanic −0.9716 (−0.637)	Pelagic-oceanic 3.750 (2.110) †	Pelagic-oceanic 3057 (4.067) ***
Weight	−0.0241 (−0.677)	−0.0121 (−0.293)	0.4209 (0.322)
Lifespan	−0.0184 (−0.426)	−0.0300 (−0.597)	−3.506 (−1.631)
Length	0.0290 (0.666)	0.0174 (0.344)	
Number of observations	25	25	59
Region (dummy)	X	X	X
R-squared	0.9331	0.8147	0.9862

4. Discussion

Our analyses suggest that the link between PBDE concentrations and stock sustainability are indirect and complex. We cannot conclude that sustainability adequately predicts PBDE contamination, given small sample sizes, larger *p*, and small R-squared values. However, we do find that intrinsic biological factors such as lifespan and body size can predict both PBDE concentrations and sustainability rankings, a conclusion supported by high R-squared values and, at times, larger sample sizes. Interestingly, trophic level was significantly linked to PBDE concentrations, though showing an indirect correlation in contrast with our prior expectations. We predicted higher concentrations of chemical contamination would be found at higher trophic levels, where typically larger, longer-lived species might have more opportunity to bioaccumulate PBDE. Our collected dataset indicates the opposite: that smaller prey species at lower trophic levels are more likely to bear high contaminant loads. This is perhaps because many lower trophic level species of fish and shellfish are also bottom dwellers living nearer to or within coastal sediments [23]. This could also indicate further complications in our use of depth as a factor, as a species' depth range does not, alone, determine its proximity to sediment or to human-populated areas. In summary, while we did not find that perceived fishery sustainability can predict PBDE contamination of fish tissue in general, our results, however, do show that life history traits of individual fish species predict both PBDE levels and our chosen sustainability metrics. The same intrinsic biological and ecological traits which facilitate the uptake of PBDEs also contribute to how species respond to fishing pressures, albeit in sufficiently distinct ways, such that stock sustainability is not a consistent indicator of PBDE contamination.

Our results should be interpreted with caution. A large number of studies reporting concentrations of PBDEs in fish were recorded in the United States, China, and the United Kingdom. It is possible that seafood PBDE contamination levels are low in South America, Africa, and India, but it is also probable that they are underrepresented in scientific studies. The costs of conducting trace contaminant analyses, including obtaining pure PBDE standards for detection and quantification and/or difficulties transporting biotic samples across country lines may be factors behind the regional skew of the collected data. We can infer from limited environmental contaminant studies that brominated flame retardants are likely present in marine and aquatic resources around the globe [24–26]. Based on analyses of our findings, in general, PBDE concentrations increase as the estimated lifespan and weight of the fish increased, and as the habitat depth decreased (Figure 2). Most research on flame retardants in fish is performed on species caught near the coast, making it difficult to statistically examine the effect of proximity to land, but we can indirectly examine this using the depth zone. We find that larger, longer-lived, and bottom-dwelling fish harvested near land are more likely to have elevated flame retardant concentrations. Pooling data on marine and freshwater fish and shellfish did not strongly influence any of our conclusions.

Another reason for caution in interpreting our findings is that the Worm et al. and MBA sustainable seafood guide information reflect relatively current fishery activities and need to be reevaluated or updated often [1]. The nature of quantifying sustainability and connections to documented PBDE concentrations creates scenarios in which the necessary variables (i.e., species included, regions represented, etc.) overlap in relatively few places, heavily limiting the sample size. The observations reported here do not represent species composition of the market; rather, they represent the composition of the literature concerning brominated flame retardants, which is limited by available resources to conduct these types of analyses. Sampling could be skewed in systematic ways—especially toward areas where contamination is likely, given the pressure to publish toxicologically meaningful results. We also excluded all farmed fish from our analysis because three of the four selected sustainability indicators apply only to wild-caught species, though aquaculture is an increasingly large part of seafood consumption. Additionally, due to inadequate data we did not examine the relationship between body fat percentage of fish in our sample and PBDE concentrations—a potentially relevant variable since PBDE and other compounds are known to accumulate in fat stores [27].

The vulnerability data values available from Fishbase.org and SeaLifebase.org are useful because they are provided for many of the world's identified fish species. However, these vulnerability values are often criticized by fishery scientists because they represent an inaccurate scaling across different species. Vulnerability is calculated by a fuzzy logic system based on 10–20 life history traits per species [18]. Most of these data do not exist for many under-studied species, leaving holes in the dataset which are glossed over by the fuzzy logic evaluation model. Despite these flaws, the vulnerability values are often considered the best broadly available index for ecological resilience across a significant number of species, provided the scientifically valid concerns are kept in mind.

Understanding the functioning of biological effects on species response to fishing pressures and uptake of chemical contaminants will become increasingly important in the Anthropocene. In light of the nuanced relationship between ecological sustainability and public health in context of flame retardant contamination, it is clear that those wishing to utilize marketing techniques to nudge seafood consumption in more sustainable directions cannot rely upon science to consistently support the finding that healthful and sustainable seafood consumption are one and the same. Instead, more nuanced and carefully calibrated messaging will be needed on the part of NGOs and government policy-makers in order to foster market-driven incentives for sustainability in the seafood supply chain while sending accurate signals to consumers about the implications of their choices for their private health and well-being.

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Developing Harvest Strategies to Achieve Ecological, Economic and Social Sustainability in Multi-Sector Fisheries

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Abstract: Ecosystem based fisheries management (EBFM) provides a framework to achieve ecological, economic and social sustainability in fisheries. However, developing harvest strategies to achieve these multiple objectives is complex. This is even more so in multi-sector multi-species fisheries. In our study, we develop such harvest strategies for the multi-species Coral Reef Fin Fish Fishery (CRFFF) operating in the waters of Australia's Great Barrier Reef. The fishery includes recreational, charter and commercial sectors, and is a provider of regional employment and supplier of seafood to both local and export markets. We convened a series of stakeholder workshops and conducted surveys to identify stakeholder objectives and priorities, as well as potential harvest strategy frameworks for the fishery. These potential harvest strategies were assessed against the objectives using a further qualitative impact survey. The analysis identified which frameworks were preferred by different stakeholder groups and why, taking into account the different objective priorities and tradeoffs in outcomes. The new feature of the work was to qualitatively determine which harvest strategies are perceived to best address triple bottom line objectives. The approach is therefore potentially applicable in other complex fisheries developing harvest strategies which, by design, strive to achieve ecological, economic and social sustainability.

Keywords: Triple bottom line fisheries management; harvest strategy development; social objectives; economic objectives; ecological objectives

1. Introduction

Ecosystem based fisheries management (EBFM) has been adopted in a wide range of jurisdictions to guide management in achieving the sustainable use of the marine resources [1]. In practice, EBFM has largely been reduced to three main dimensions—ecological, human, and governance—where ecological criteria focus on one or more aspects of ecosystem complexity; human dimension criteria integrate social and economic factors and involve stakeholders in the ecosystem planning processes; and governance criteria include a range of administrative structures (e.g., co-management) and processes to ensure the desirable outcomes are achieved [2]. The success of EBFM to date, however, has been limited due to three key impediments: a relative lack of explicit social, economic and institutional objectives; a general lack of process (frameworks, governance) for routine integration of all dimensions of sustainability; and a historical emphasis on biological considerations, especially those related to fished stocks [3]. Definitive research on appropriate ways to select and assess social objectives for fisheries is relatively recent [4]. What tends to be lacking is the inclusion of all three dimensions directly within harvest strategies.

The recent Queensland Sustainable Fisheries Strategy [5] aims to move the state's fisheries towards a more ecologically, economically and socially sustainable future. As part of this process, a number of Fisheries Working Groups have been established to identify fishery objectives and harvest strategies aimed at moving the fisheries forward. These Working Groups include a wide range of stakeholders, including all fisher sectors (commercial, charter and recreational); processors and buyers; scientists, fishery managers, marine park managers and conservation groups.

The aim of this paper is to outline the process undertaken to develop a harvest strategy for a complex multi-sector fishery to achieve ecological, economic and social sustainability objectives. The Coral Reef Fin Fish Fishery (CRFFF) is one of Queensland's most valuable in terms of export earnings, and has important recreational, commercial and charter sectors [6].

Consistent with the principles of EBFM, the process developed in this paper involved first identifying and prioritizing the objectives for the fishery with the key stakeholders. Given these objectives, modifications to the current harvest strategy were then developed that potentially considered these broader objectives. The effectiveness of these additions at improving performance was examined through a qualitative impact assessment against the objectives. The overall subjective probabilities that the options would improve the fishery's outcomes were determined.

The process provides a roadmap for future harvest strategy development to achieve ecological, economic and social objectives. The paper is organized as follows. First, an outline of the fishery is presented in order to set the context of the analysis. Second, the methods used to elicit objectives and objective weights, develop the harvest strategies and qualitatively determine the impact of the alternative harvest strategy options are described. Next, the fishery specific outcomes are presented. Finally, implications for future development of harvest strategies to achieve ecological, economic and social outcomes are discussed.

2. The Coral Reef Fin Fish Fishery (CRFFF)

Queensland's CRFFF targets primarily demersal reef-associated fish and operates predominantly in the Great Barrier Reef Marine Park, which includes no-take areas for biodiversity protection that restrict where this fishery can operate while providing some benefits to populations of fished species [7,8]. The Great Barrier Reef Marine Park stretches approximately 2300 km along the coast of Queensland from the northern tip of north-eastern Australia. It covers 344,400 km^2 of the world's largest coral reef ecosystem, and includes some 3000 coral reefs, 600 continental islands, 300 coral cays and about 150 inshore mangrove islands. The fishery is managed by Fisheries Queensland (the state's fisheries management agency) under the *Fisheries Act 1994* (QLD) and *Fisheries Regulation 2008*, and includes both input (including maximum vessel size, gear restrictions, area and seasonal closures) and output (Total Allowable Commercial Catch (TACC) limitations, individual transferable quotas (ITQs) size and possession limits) controls. Further details on management arrangements in the fishery can be found in Thébaud, et al. [9].

The fishery is multi-species in nature and the key commercial species groups include coral trout and red throat emperor, and a range of cods, groupers, emperors, tropical snappers, sea perches, and wrasses [10]. The market for landings can be divided into two main components: a high-value export market which developed in the mid-1990s and consists predominantly of live coral trout for the Asian food fish trade, and a domestic market which consumes mainly dead fish (both fresh and frozen) and is more multi-species. In the 2016–17 financial year, the gross value product of the commercial fishery was AUD 31.1 m, with each active vessel landing fish valued at around AUD 125,000 on average per annum [11].

In the commercial fishery, fishers use lines and operate from small tender vessels powered by an outboard motor. The tenders also use a main vessel as a "mother ship" for storage of the catch (as well as occasionally operating as a fishing platform). The use of multiple tenders enables the fishers to cover more area of the reef on any trip and access areas too shallow to fish from the primary vessel. A number of the vessels may also participate in other fisheries, e.g., using gillnets (for inshore fish species), trolls (for mackerel) and pots (for crabs).

Output controls in the form of TACCs and ITQs were introduced into the fishery in 2004. Commercial license holders were allocated reef quota (RQ) shares based on historical catch records associated with their license. There are three types of RQ quota: coral trout (CT), red throat emperor (RTE), and other species (OS), the latter being a collective of approximately 154 other reef fish species of which only a relatively small proportion are actively targeted by the commercial fishery. CT quota covers seven separate species of coral trout but the majority of the landings, and almost all exports, consist of the common coral trout (*Plectropomus leopardus*). All quota is fully tradable, in both permanent and temporary (lease) trades. Leased quota automatically reverts back to the owner at the end of each year.

The fishery also has a substantial recreational component. Recreational fishing is an important social and economic activity in the region [12], with some studies estimating that recreational fishing has nearly the same economic contribution to the Great Barrier Reef region as commercial fishing [13]. The recreational sector is predominantly based on private vessels on day trips, mostly fishing closer inshore than the commercial or charter sectors [14]. However, given the common species targeted, the two fisheries are biologically entwined. Recreational fishers are managed through size and possession limits (a maximum of two of each species, with a combined possession limit of 20 in total of all coral reef fin fish).

Associated with the recreational sector is a commercial charter sector. Since 2006, licensed charter fishing operators in the area of the fishery have been required to pay an annual management fee and report catches in logbooks. The vessels are also subject to trip limits based on the number of recreational fishers onboard and the length of the trip; i.e., the number of recreational fishers multiplied by the individual fisher's recreational possession limits [15]. Extended limits apply for continuous trips between 72 h and 160 h where double the possession limit applies; trips over 160 h allow three times the possession limit.

As with most fisheries, stocks in the CRFFF are affected by environmental fluctuations. Being in a tropical environment, cyclones are regular occurrences which can damage the key habitats in parts of the fishery and have also affected catchability with flow on effects to fishery operations [16]. In more recent years, coral bleaching events related to climate change have been more frequent, also adversely affecting the species' habitats and their ability to support the species [17,18].

3. Materials and Methods

3.1. Identification of Management Objectives

Considerable work has previously been undertaken examining management objectives in fisheries. Previous studies of fisheries management objectives (and natural resource management objectives in general) have generally identified a hierarchy of objectives, with higher level objectives being the typical triple bottom line categories of ecological, economic and social objectives, and lower level objectives being more detailed or specific objectives for the fishery in question [19–24]. A similar approach was adopted for this study, although a fourth higher level objective—enhancing management performance—was also included as this had been previously considered important by both managers and fishers [25]. Consideration of institutional objectives is also considered best practice in developing good management [3].

An initial review of objectives that had previously been applied in Australian fisheries was undertaken, and a total of 75 different potential objectives were identified. A series of workshops were held with members of the CRFFF Working Group to identify the triple bottom line objectives that were of most relevance to the fishery. The group formally includes 12 industry members (four commercial fishers, two recreational fishers, one charter operator, one export/marketing representative, one scientific member, one compliance (boating patrol) member, one Great Barrier Reef Marine Park Authority (GBRMPA) representative and one conservation non-governmental organization (NGO) representative) supported by 2–3 managers (see [26] for more information on the CRFFF Working Group). However, with not all members being available at all times, and substitutes provided, some 20 different individuals were involved in the discussions.

In the first of these meetings, stakeholders were assisted by providing the list of these 75 identified objectives, as well as some example objectives identified in an earlier Queensland study [25] and the concepts around the development of an objective hierarchy. Working Group members broke into smaller groups to identify which of these earlier objectives may be applicable to their fishery, which needed modification, and which new objectives specific to their fishery were required. A revised potential set of objectives was then compiled based on the outcomes from the group discussions.

Between meetings, the project team translated each of these potential conceptual objectives into operational objectives. To be considered operational, they needed to be realistic, be simulation-achievable (i.e., testable through management strategy evaluation), and have performance indicators against which each objective could be assessed.

A revised set of potential objectives was presented at the subsequent Working Group meeting, and the final set of 22 operation objectives for the fishery was identified through further discussion with the Working Group.

3.2. Objective Weighting Approaches

Different harvest strategies are likely to have different impacts against the different objectives. Additionally, individuals will assign different preferences to the objectives. To assess the overall suitability of the harvest strategy, the objectives need to be weighted according to stakeholder preferences, so that the different strategies can be compared on an effective performance basis. A range of methods has been applied in the literature to assess objective weights, each with advantages and disadvantages [27–32]. Comparative studies of these methods suggest in some cases that the objective weights may vary considerably between methods [33], although others have found higher correlations between the results of the different methods [34].

For this study, we applied a modified version of the analytic hierarchy process (AHP) [35] through an online survey of fishery stakeholders to elicit weights. AHP has been used in a number of marine and coastal applications to determine management sub-component importance and assist in decision making [19,20,23,25,36–40], and is the most common approach used for preference elicitation in applied natural resource case studies. Traditional AHP is based upon the construction of a series of pair-wise comparison matrices which compare sub-components to one another, and a hierarchical structure that groups similar sub-components into subgroups, and builds the hierarchy with progressive layers of groupings. The pair-wise comparison used in the traditional AHP method makes the process of assigning weights much easier for participants because only two sub-components are being compared at a time.

A challenge facing the use of traditional AHP is the propensity for respondents to be unintentionally inconsistent in their responses. Preference weightings are highly subjective, and inconsistency between responses to different combinations of comparisons is a common problem facing AHP, particularly when decision makers are confronted with many sets of comparisons [41]. Respondents do not necessarily cross check their responses, and even if they do, ensuring a perfectly consistent set of responses when many sub-components are compared is difficult. The discrete nature of the 1–9 scale in the traditional AHP approach can also contribute to inconsistency, as a perfectly consistent response may require a fractional preference score. Inconsistency can also arise through errors in entering judgments, lack of concentration and inappropriate use of extremes [40].

In natural resource management particularly, management agencies are turning to online surveys to understand the priorities of a wide range of stakeholders, better support policy development and management decision making, with many of these surveys using AHP approaches (e.g., [42–47]). The use of online surveys to elicit preferences is not unique to natural resource management, with a range of other AHP studies implemented through online surveys (e.g., [48,49]). A key advantage of the use of online surveys is that they allow access by relevant stakeholders who may be geographically dispersed, even if not large in absolute numbers (for example, see Thadsin, et al. [50]).

The lack of direct interaction with the respondents creates additional challenges for deriving priorities through approaches such as AHP. Direct interaction with the individual respondents is generally not feasible, and in many cases responses are anonymous. At the same time, levels of inconsistency tend to be high in online surveys. For example, Hummel, et al. [51] found that when their survey was conducted online, only 26% of respondents satisfied a relaxed threshold consistency ratio of 0.3 (compared to the standard threshold of 0.1); Sara, et al. [52] found 67% of respondents satisfied a relaxed threshold consistency ratio of 0.2; Marre, et al. [47] found 64% of the general public and 72% of resource managers provided consistent responses, while Tozer and Stokes [53] found only 25% or respondents satisfied the standard threshold consistency ratio. Most previous online-based AHP studies have tended to exclude responses that have a high level of inconsistency, resulting in a substantially reduced, and potentially unrepresentative, sample size (e.g., [47,51–53]).

In this study, we avoid some of these pitfalls by modifying the way in which the data are collected and analyzed, taking into account the symmetry assumption underlying AHP. In our survey, respondents were presented with a nine-point importance scale against which they could assess the importance of each objective. A nine-point scale was selected (rather than an "out of 10") as it allows five categories to be defined with mid-points between them, and is also consistent with the traditional AHP approach. An example of one of the questions is presented in Figure 1. The complete questionnaire is provided in the Supplementary Material.

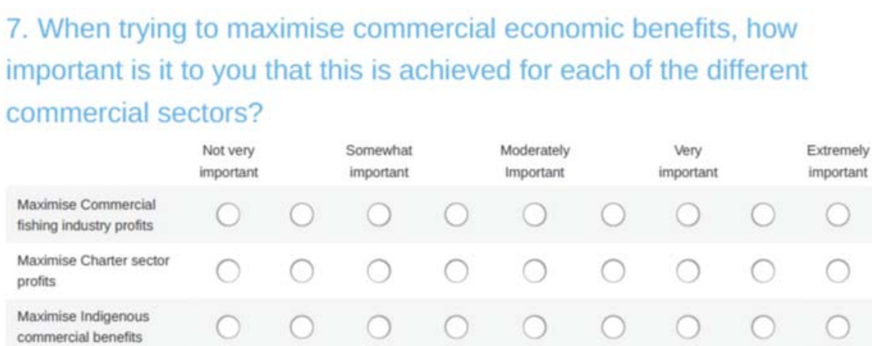

Figure 1. Example question in the objective importance survey.

In the approach used in this study, a separate value is derived for each objective (e.g., $a_i = 1$ to 9) given the importance level identified in Figure 1, and the relative score between any two objectives, α *i,j*, is derived from the difference between them. This can be estimated by

$$a_{i,j} = \begin{cases} a_i - a_j + 1 \; if \; a_i - a_j > 0 \\ \frac{-1}{a_i - a_j - 1} \; if \; a_i - a_j \leq 0 \end{cases} \quad and \; a_{j,i} = \frac{1}{a_{i,j}} \qquad (1)$$

Preferences are assumed to be symmetrical, such that if the relative importance of Objective 1 compared with Objective 2 has a value of $\alpha_{12} = 9$, then $\alpha_{21} = 1/\alpha_{12} = 1/9$. For each set of comparisons, a comparison matrix of scores (A) can be developed, given by:

$$A = \begin{bmatrix} 1 & a_{12} & \ldots & a_{1n} \\ a_{21} & 1 & \ldots & a_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ a_{n1} & a_{n2} & \ldots & 1 \end{bmatrix} \quad (2)$$

Given the derived matrix of relative objective importance, t(A) here are two general approaches used for determining the weights: the original eigenvalue method (EM) developed by Saaty [35] and the geometric mean method (GMM) developed by Crawford and Williams [54] (alternative approaches have also been used to derive the weights, with the row geometric method [54] gaining increasing interest [55]). While the former approach has been employed in a wider range of coastal and resource management studies, the latter has been found to be less susceptible to the influence of extreme preferences, as well as having better performance around other aspects of theoretical consistency (e.g., less susceptible to rank reversibility if the preference set changes, and greater transitivity properties) [55].

The objective weights (ω_i) using the GMM are determined by:

$$\omega_i = \frac{\left(\prod_{j=1}^{n} a_{i,j}\right)^{1/n}}{\sum_i \left(\prod_{j=1}^{n} a_{i,j}\right)^{1/n}} \quad (3)$$

where $\prod_{j=1}^{n} a_{i,j} = a_{i,1} \times a_{i,2} \times \ldots \times a_{i,n}$ (i.e., the product of the elements of row i), and n is the total number of objectives being compared.

The analysis is undertaken within each level of aggregation in the hierarchy. That is, level one objectives are first compared with each other (e.g., the broad ecological, economic, management and social objectives) to estimate the broad category weight (e.g., ω_1, ω_2, ω_3, ω_4). Then, level two objectives within each of the broader objectives (i.e., the sub-objectives within a given level one objective) are compared to produce their relative weights within the broader objective (e.g., $\omega_{1.1}$, $\omega_{1.2}$, ... , $\omega_{1.n}$, then $\omega_{2.1}$, $\omega_{2.2}$, ... , $\omega_{2.n}$, etc.). Finally, the level three objectives within each of the level two objectives are compared to produce their relative weights (e.g., $\omega_{1.1.1}$, $\omega_{1.1.2}$, ... , $\omega_{1.1.n}$). The overall weight of an individual operational is determined by the product of its initial weight estimate (i.e., when compared with other sub-components in that same group) multiplied by the weight of the higher order aggregation (i.e., compared with other higher order aggregations) under the principle of hierarchic composition [56]. For example, the final overall weight for objective 1.1.1 is given by $\omega_{1.1.1}$ * $\omega_{1.1}$ * ω_1. This reduces the number of necessary direct comparisons, as only sub-components at the same level and within the same broader sub-component need to be compared.

An advantage of this approach over the traditional pair-wise comparison is that the respondent is able to compare all objectives within the comparison set at the same time, avoiding issues around inconsistency (which does not need to be calculated as a result). That is, the respondent will immediately be able to see how each objective compares with the others in the comparison set when making their response.

The online survey was developed in Survey Monkey. The survey was distributed to stakeholders in the fishery with the assistance of Fisheries Queensland (the management agency) and the members of the Working Group.

3.3. Identification of Potential Harvest Strategies

A range of potential harvest strategies were developed in collaboration with the CRFFF Working Group through a series of workshops. Initially, information was fed back to the Working Group about the outcomes of the objectives surveys to help identify key areas that required further consideration. The Working Group first established a "modified status quo" option (the "baseline") which was considered the minimum amount of change required to meet the ecological sustainability objectives of the new Queensland Sustainable Fisheries Strategy [5]. A number of other alternatives were identified that were believed to enhance at least one or more of the broader objectives of the fishery.

The proposed harvest strategies are briefly described below to place subsequent sections of the paper in context. A more detailed description of the proposed harvest strategies is included in the Supplementary Material.

The key proposed modification underlying the "modified status quo" harvest strategy was the adoption of a target reference point for the stocks of 60% of the unexploited biomass, which is consistent with the Queensland Sustainable Fisheries Strategy [5]. This reference point was taken as a proxy for the biomass at maximum economic yield and to provide biological resilience to the stock. Harvest control rules were developed to adjust the fishery-level total allowable catch (TAC) each year, where these changes are then proportionally applied to both the commercial catch limit (TACC) and the recreational catch limits to maintain relative equity between the sectors. For coral trout species, the combined TAC is based on a stock assessment every 5 years and a suite of other indicators in the intermediate years. For red throat emperor, the changes are proposed to be based on a risk assessment undertaken at least every 5 years, with empirical indicators used to adjust the quota and possession limits in the intermediate years. Similarly, for the other species (OS) component, the combined TAC would be retained, with both commercial and recreational catches proportionally adjusted in response to changes in the level of catch and catch composition. Within this cap, species considered "at risk" would potentially be subject to separate commercial caps and recreational trip limits.

Alternative harvest strategies identified by the Working Group were believed to further enhance one or more ecological, economic or social objectives. These included (i) a separate allocation of the TAC to the charter sector (managed through vessel-level possession limits, as opposed to being based on the number of recreational fishers they carried), aimed at enhancing the economic performance of this sector and social benefits accruing to the recreational fishers using these vessels; (ii) the use of environmental "overrides" where TACs are adjusted in response to a spatially or temporally isolated weather event (e.g., a tropical cyclone) to enhance ecological outcomes and long term fishery performance; (iii) the combination of environmental overrides and spatially explicit management, where responses to the catastrophic event may vary in different areas of the fishery and also to ensure some form of spatial equity across regional communities; (iv) formally identifying separate TACs for a number of key OS quota species with ITQs and possession limits also allocated for these species; and, (v) formally identifying separate TACs for a number of key coral trout species, again with separate ITQs and possession limits for each of these species for largely ecological benefits.

It was recognized that these different alternative options would have greater benefits than the modified status quo against some objectives but potentially reduce benefits against others. A subsequent further analysis was hence undertaken to qualitatively assess the relative benefits of these alternative harvest strategy proposals.

3.4. Performance of Each Harvest Strategy against the Objectives

The assessment of the performance of the alternative harvest strategies against each of the objectives followed a similar approach as that outlined in [57] and Dichmont, et al. [43]. However, where in those approaches several distinct harvest strategies were scored, in this paper additional components to the "modified status quo" were assessed. A second online survey was developed in Survey Monkey aimed at eliciting "expert" opinion as to the effects of the management options on the objective outcomes. The main target of the second survey was members of the CRFFF Working

Group who had taken part in developing the set of management objectives and harvest strategies, and most likely had expectations about how they would perform. Given the small number involved in this group, the survey was also administered to those individuals from the first survey who had agreed to participate in a follow-on survey (other than the working group members).

The respondents of the second survey were asked to rate each potential harvest strategy relative to the baseline (i.e., the modified status quo) against each objective on a scale ranging from of "Much worse than the baseline" to "Much better than the baseline". An example of one such comparison applied in the survey is given in Figure 2. The complete questionnaire is provided in the Supplementary Material.


Objective 1.1.1. Achieve BMEY by 2027 and BMSY by 2020 (or sooner) for the main commercial, charter and recreational species

	Much worse than baseline	Worse	Slightly worse	About the same as the baseline	Slightly better	Better	Much better than baseline
Baseline PLUS separate charter allocation	○	○	○	○	○	○	○
Baseline PLUS environmental overrides	○	○	○	○	○	○	○
Baseline PLUS spatially explicit control rules AND environmental overrides	○	○	○	○	○	○	○
Baseline for CT and RTE, but with split TACs for OS	○	○	○	○	○	○	○
Baseline for CT, RTE, and OS, but with the additional CT species explicitly considered	○	○	○	○	○	○	○

Figure 2. Example question in the harvest strategy performance survey.

The resultant choices were converted to a 7-point scale, ranging from −3 ("Much worse than the baseline") to +3 ("Much better than the baseline"), with "About the same as the baseline" having a value of 0. The final output of this process is an $(i * j)$ impact matrix, I^s, for each strategy s, where i is the number of objectives and j is the total number of respondents of the second survey.

The relative weights for each respondent for each objective derived from the objective survey were combined into a single $(r * i)$ relative weight matrix, W^t by stakeholder group, t, where r is the number of respondents to the objective survey and i is the number of objectives considered. The overall results were derived by the product of these two matrices, $W'I$ for each stakeholder group and harvest strategy, producing $(r*j)$ observations, providing a score representing how well the harvest strategy performs against the baseline given the objective preference of each respondent r and the expectations about how the strategy performs against these objectives from each respondent j. A positive score indicates that the strategy is better than the present system, while a negative score indicates that the strategy is worse. In this regard, the resultant scores are similar in principle to utility measures, and the process for assessing the subjective probabilities or an outcome similar to those used in multi-attribute utility theory [58].

From the relative frequencies of these scores, we are able to derive a subjective probability distribution [59] of the expected benefits of each harvest strategy that takes into account heterogeneity in both the impact scores and also the objective preference weightings. The probability distributions are subjective rather than objective as they are based on distributions of opinion and expert judgement rather than actual real-world outcomes.

3.5. Ethical Clearance

The surveys and workshops were approved by CSIRO's (Commonwealth Scientific and Industrial Research Organisation) Social Science Human Research Ethics Committee (Project 113/17) in accordance with the Australian National Statement on Ethical Conduct in Human Research. As the surveys were sequential, each was submitted separately for review and clearance before being implemented.

4. Results

4.1. Identification and Weighting of Objectives

A total of 22 operational objectives were agreed by the Working Group (Table 1). These were arranged into a three-level hierarchy, with the top level consisting of ecological sustainability, economic, governance (management) and social objectives.

A number of other objectives (mostly governance and social objectives) were also considered important by the Working Group, but it was recognized that these could not be influenced by a harvest strategy, and were not subsequently considered in the further analysis as they would not be affected by the scoring system. For example, one such management objective—transparent decision making—is a function of the governance structure rather than a feature of any particular harvest strategy. It was noted that these additional objectives would need to be considered when developing broader management structures.

4.1.1. Objective Weighting Survey Responses

The objective weighting survey received a total of 110 responses, of which around half were from commercial fishers (Figure 3). Most respondents identified as one of two different stakeholder groups, with the biggest overlap being between the commercial fishers and quota holders. Only three responses were received from conservation groups, so these were incorporated into the "other" category, which also contains commercial and recreational fisheries association representatives (but who were not active fishers in the CRFFF), and quota brokers.

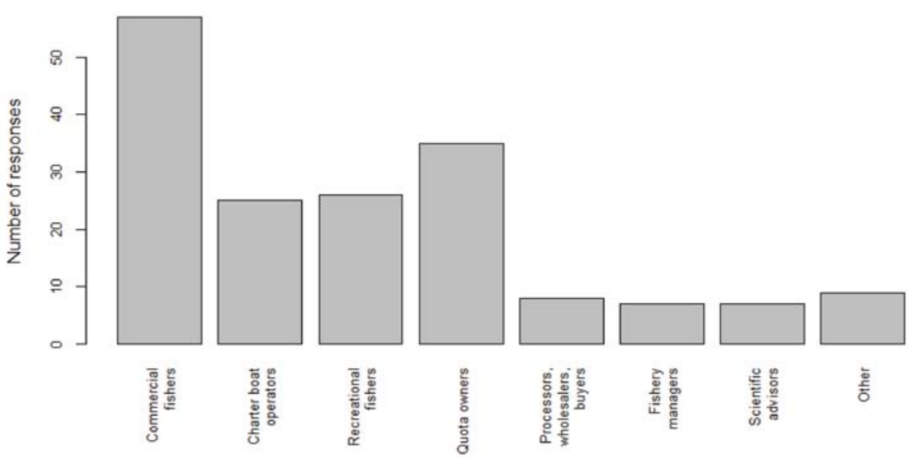

Figure 3. Distribution of survey responses by stakeholder group.

Table 1. Objective hierarchy identified with the Working Group.

Broad Objectives (Level 1)	Sub-objectives (Level 2)	Specific Operational Objectives (Level 3)
1. Ensure ecological sustainability	1.1 Ensure resource biomass sustainability	1.1.1 As per the Queensland Sustainable Fisheries Strategy, achieve B_{MEY} (biomass at maximum economic yield) (~60% unfished biomass or defensible proxy), by 2027 for the main commercial, charter and recreational species; if below biomass at maximum sustainable yield, B_{MSY}, aim to achieve B_{MSY} (~40–50% B_0) by 2020. 1.1.2 Minimize risk to Other Species in the fishery which are not included in 1.1.1.
	1.2 Ensure ecosystem resilience	1.2.1 Minimize risk to bycatch species 1.2.2 Minimize discard mortality of target species (e.g., high grading) 1.2.3 Minimize broader ecological risks 1.2.4 Minimize risk to protected species
	1.3 Minimize risk of localized depletion	1.3.1 Minimize risk of localized depletion due to fishing 1.3.2. Minimize risk of localized depletion in response to environmental events (e.g., cyclone)
2. Enhance fishery economic performance	2.1 Maximize commercial economic benefits, as combined totals for each of the following sectors	2.1.1 Commercial fishing industry profits 2.1.2 Charter sector profits 2.1.3 Indigenous commercial benefits
	2.2 Maximize value of recreational fishers and charter experience (direct to participant)	2.2 Maximize value of recreational fishers and charter experience
	2.3 Maximize flow-on economic benefits to local communities (from all sectors)	2.3 Maximize flow-on economic benefits to local communities
	2.4 Minimize short term (inter-annual) economic risk	2.4 Minimize short term (inter-annual) economic risk
	2.5 Minimize costs of management associated with the harvest strategy: monitoring, undertaking assessments, adjusting management controls	2.5 Minimize costs of management associated with the harvest strategy: monitoring, undertaking assessments, adjusting management controls
3. Enhance management performance	3.1 Maximize willingness to comply with the harvest strategy	3.1 Maximize willingness to comply with the harvest strategy
4. Maximize social outcomes	4.1 Maximize equity between recreational, charter, indigenous and commercial fishing	4.1 Increase equitable access to the resource
	4.2 Improve social perceptions of the fishery (social license to operate) (recreational, commercial, charter, indigenous)	4.2.1 Through sound fishing practices, minimize adverse public perception around discard mortality (compliance with size limits, environmental sustainability, and waste) 4.2.2 Maximize utilization of the retained catch of target species 4.2.3 Maximize the potential for fishing to be perceived as a positive activity with benefits to the community (commercial, rec, and charter)
	4.3 Enhance the net social value to the local community from use of the resource	4.3.1 Increase access to local seafood (all species) 4.3.2 Maximize spatial equity between regions or local communities

4.1.2. Objective Importance

The distributions of the derived higher-level objective groups (Ecological Sustainability, Economic, Management, and Social) by stakeholder group are shown in Figure 4. All groups tended to rank the ecological sustainability objectives the highest. The commercially oriented groups (commercial fishers, quota owners and buyers) also generally rated economic objectives similar to the ecological sustainability objectives, whereas the other groups tended to rate economic objectives lower than ecological sustainability. Charter operators were closer to recreational than commercial weightings. Most groups tended to rate the social objectives the lowest, consistent with most other previous management objective studies in Australia [24,60].

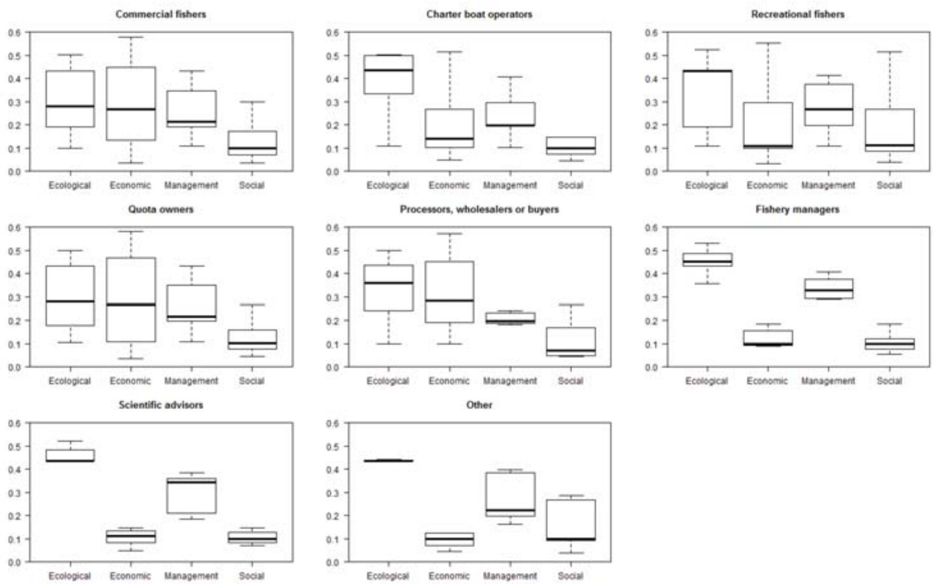

Figure 4. Objective weight distributions by stakeholder group. The thick bar represents the median weight; the box represents the range of weights between the 75th and 25th percentile (i.e., 50% of the observations); the "whiskers" represent the upper and lower bounds of the distribution.

The full set of average objective weightings are given in Table 2. The weightings on the lower level objectives appear fairly similar across the different stakeholder groups. This is an artefact of the "dilution" effect of distributing the higher-level objective weights over many sub-objectives. The cumulative effect of these small differences at the lower level, however, may result in overall different preferences for different harvest strategies at the stakeholder level.

Table 2. Average weights by stakeholder group.

Group	Commercial Fishers		Charter Boat Operators		Recreational Fishers		Quota Owners		Processors/ Wholesalers/ Buyers		Fishery Managers		Scientific Advisors		Other	
Responses		**57**		**25**		**26**		**35**		**8**		**7**		**7**		**9**
	Mean	RSE	Mean	RSE	Mean	RSE	Mean	RSE	Mean	RSE	Mean	RSE	Mean	RSE	Mean	RSE
Ecol1	0.308	3%	0.384	3%	0.335	3%	0.297	3%	0.387	3%	0.454	3%	0.461	3%	0.405	3%
Ecol1.1	0.100	4%	0.130	4%	0.124	4%	0.110	4%	0.207	4%	0.254	4%	0.193	4%	0.138	4%
• Ecol1.1.1	0.058	6%	0.055	6%	0.070	6%	0.064	6%	0.133	6%	0.170	6%	0.093	6%	0.062	6%
• Ecol1.1.2	0.042	6%	0.075	6%	0.054	6%	0.046	6%	0.074	6%	0.083	6%	0.100	6%	0.076	6%
Ecol1.2	0.109	5%	0.132	5%	0.115	5%	0.101	5%	0.099	5%	0.120	5%	0.191	5%	0.133	5%
• Ecol1.2.1	0.022	7%	0.023	7%	0.026	7%	0.018	7%	0.018	7%	0.016	7%	0.040	7%	0.027	7%
• Ecol1.2.2	0.037	5%	0.045	5%	0.038	5%	0.039	5%	0.039	5%	0.038	5%	0.044	5%	0.051	5%
• Ecol1.2.3	0.028	6%	0.033	6%	0.027	6%	0.023	6%	0.027	6%	0.033	6%	0.054	6%	0.029	6%
• Ecol1.2.4	0.023	6%	0.031	6%	0.024	6%	0.020	6%	0.016	6%	0.033	6%	0.053	6%	0.026	6%
Ecol1.3	0.099	5%	0.122	5%	0.096	5%	0.087	5%	0.081	5%	0.080	5%	0.077	5%	0.134	5%
• Ecol1.3.1	0.066	6%	0.084	6%	0.061	6%	0.061	6%	0.038	6%	0.044	6%	0.051	6%	0.073	6%
• Ecol1.3.2	0.033	7%	0.038	7%	0.035	7%	0.025	7%	0.042	7%	0.036	7%	0.027	7%	0.062	7%
Econ2	0.286	4%	0.239	4%	0.214	4%	0.289	4%	0.311	4%	0.125	4%	0.123	4%	0.169	4%
Econ2.1	0.099	5%	0.062	5%	0.053	5%	0.098	5%	0.094	5%	0.033	5%	0.035	5%	0.036	5%
• Econ2.1.1	0.064	7%	0.023	7%	0.025	7%	0.064	7%	0.057	7%	0.017	7%	0.016	7%	0.023	7%
• Econ2.1.2	0.018	7%	0.031	7%	0.020	7%	0.019	7%	0.024	7%	0.008	7%	0.010	7%	0.008	7%
• Econ2.1.3	0.017	8%	0.008	8%	0.008	8%	0.015	8%	0.013	8%	0.008	8%	0.009	8%	0.006	8%
Econ2.2	0.023	8%	0.043	8%	0.053	8%	0.025	8%	0.036	8%	0.032	8%	0.014	8%	0.018	8%
Econ2.3	0.061	6%	0.057	6%	0.048	6%	0.060	6%	0.086	6%	0.022	6%	0.032	6%	0.059	6%
Econ2.4	0.050	6%	0.036	6%	0.028	6%	0.052	6%	0.043	6%	0.018	6%	0.019	6%	0.026	6%
Econ2.5	0.053	5%	0.041	5%	0.032	5%	0.055	5%	0.053	5%	0.020	5%	0.022	5%	0.030	5%
Manage3	0.264	4%	0.232	4%	0.277	4%	0.271	4%	0.241	4%	0.317	4%	0.293	4%	0.270	4%
Social4	0.142	4%	0.145	4%	0.174	4%	0.143	4%	0.061	4%	0.104	4%	0.123	4%	0.156	4%
Social4.1	0.033	7%	0.047	7%	0.048	7%	0.038	7%	0.016	7%	0.038	7%	0.045	7%	0.039	7%
Social4.2	0.048	5%	0.051	5%	0.056	5%	0.051	5%	0.021	5%	0.029	5%	0.037	5%	0.067	5%
• Social4.2.1	0.010	6%	0.011	6%	0.013	6%	0.011	6%	0.006	6%	0.008	6%	0.006	6%	0.017	6%
• Social4.2.2	0.017	6%	0.018	6%	0.018	6%	0.018	6%	0.005	6%	0.012	6%	0.016	6%	0.021	6%
• Social4.2.3	0.021	6%	0.022	6%	0.026	6%	0.022	6%	0.010	6%	0.009	6%	0.015	6%	0.029	6%
Social4.3	0.061	6%	0.047	6%	0.070	6%	0.054	6%	0.024	6%	0.037	6%	0.041	6%	0.050	6%
• Social4.3.1	0.039	7%	0.023	7%	0.032	7%	0.034	7%	0.013	7%	0.017	7%	0.026	7%	0.035	7%
• Social4.3.2	0.022	6%	0.024	6%	0.038	6%	0.02	6%	0.012	6%	0.021	6%	0.015	6%	0.016	6%

4.2. Performance of Harvest Strategies against the Objectives

A second questionnaire to assess each of the potential harvest strategies (described in Section 3.3 and detailed in the Supplementary Material) against each of the objectives was developed and sent to a smaller group of stakeholders. As the aim of the second survey was to elicit expert opinion as to how each of the potential harvest strategies might perform against the different fisheries objectives, the main target was the Working Group members, who were familiar with both the proposed harvest strategies and the objectives. However, as this group was relatively small (12 stakeholder members plus 2–3 managers), additional responses were elicited from other stakeholders with a prior involvement with the project. From the first survey of management objective importance, 48 respondents expressed a willingness to participate in a follow up survey (including working group members), and this broader group was approached.

Working Group members were notified in advance about the second survey and agreed to a short turnaround time. The survey was administered during a fishery closure, during which time all commercial fishers were onshore. The survey was only open for one week (the last week of the closure), during which 28 responses were received. From these, a total of 18 useable responses were received, with the other 10 respondents only providing details of their involvement with the fishery and no assessments of the harvest strategy options. Four respondents answered most, but not all of the harvest strategy related questions. These were included in the set of usable responses, with the average response of the rest of the group used to replace the missing values in the subsequent analyses. Two-thirds (12) of the usable responses were from Working Group members, with the remainder from individuals not involved in determining the harvest strategies. The distribution of the responses by stakeholder group is shown in Figure 5.

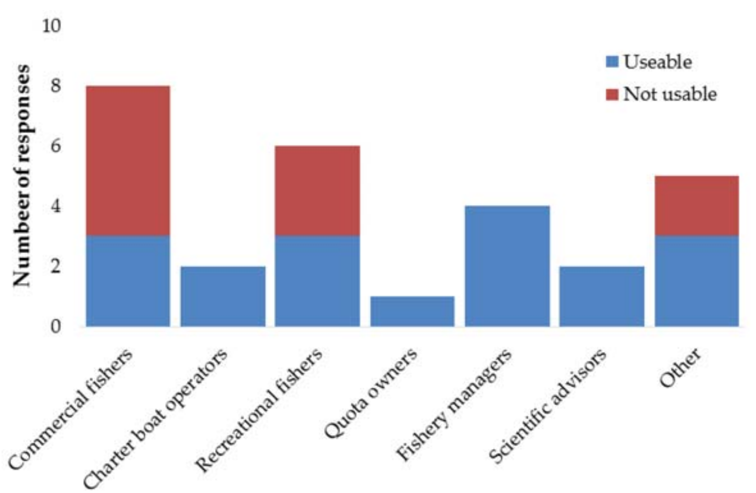

Figure 5. Impact survey response by stakeholder group.

4.2.1. Harvest Strategy Impacts

The expected (perceived) impact of each harvest strategy option against the objectives is shown in Figure 6. The charter sector allocation option is generally expected to provide benefits against nearly all objectives, with the possible exception of two objectives: discard mortality (Ecol1.2.2) (possibly due to a perception of some respondents that the quota will encourage high-grading and discarding as in commercial fisheries, although the current recreational trip limits are also essentially a quota) and costs of management (Econ2.5) (possibly due to a perception of higher monitoring, surveillance and control costs). The addition of environmental overrides is generally considered to have ecological sustainability benefits, but potentially negative consequences for the economic objectives. Social outcomes are expected to be mixed, with improvement against some objectives (e.g., Social4.2.1 and Social4.2.3, both relating to improved social perceptions) and losses in other areas (Social4.3.1—access to local seafood). The addition of spatially explicit control rules and environmental overrides is expected to produce a similar pattern with respect to ecological and economic outcomes as the previous option, although the magnitude and uncertainty around some of these impacts is greater (e.g., Ecol1.1.2, Ecol1.2.1, Ecol1.2.3, Econ2.2).

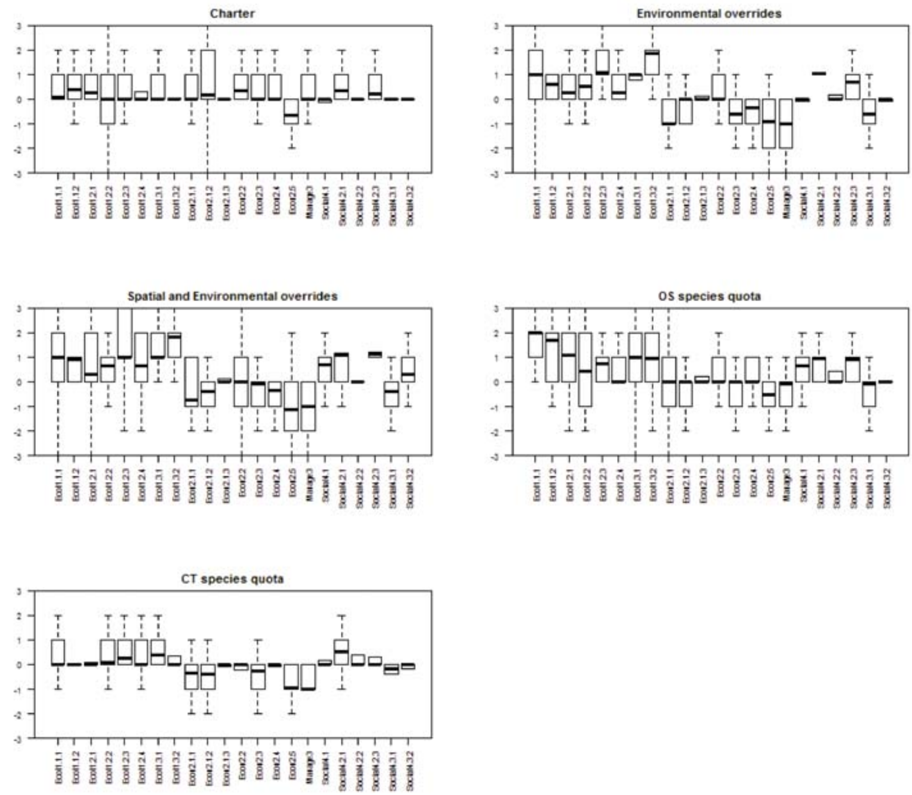

Figure 6. Distribution of the impacts against the management objectives. The thick bar represents the median weight; the box represents the range of weights between the 75th and 25th percentile (i.e., 50% of the observations); the "whiskers" represent the upper and lower bounds of the distribution.

Separating out some of the OS species and applying TACs to these is expected to potentially have more substantial ecological benefits, with a mixed result in terms of economic objectives. With a large number of species included in the OS quota, separating out key species is likely to improve their ecological sustainability. In contrast, separating out the coral trout species into separate TACs is expected to have little or no ecological benefit (as there are only a small number of species covered by this quota), but would entail economic costs.

Willingness to comply with management regulations (Manage3) is also likely to vary with the different potential harvest strategies. With the exception of the separate charter allocation, and to a lesser extent the OS species quotas, willingness to comply is expected to decrease, with the greatest decreases being expected with the two environmental override options. These options potentially impose additional restrictions on the fishery (in response to environmental events), and hence may attract additional opposition by fishers.

4.2.2. Overall Performance Measures of Each of the Harvest Strategies

The derived impact matrix was multiplied by the matrix of objective weights (i.e., $W'I$) to produce a matrix of potential weighted scores for each of the harvest strategy options, with each score ranging from −3 to 3. The distributions of these scores are illustrated in Figure 7. For each of the 18 expert assessments of the impact of the strategy on the objectives, there are 110 weighted scores reflecting heterogeneity in the importance of these objectives; or for each of the 110 individuals providing the objective importance weights, there are 18 different weighted scores associated with each strategy representing the uncertainty in the effects of the strategy on the objectives. In total, 1980 subjectively weighted scores are estimated for each harvest strategy reflecting both heterogeneity in the stakeholder groups and uncertainty in the expert assessments. All experts and stakeholders are assumed to have equal weight.

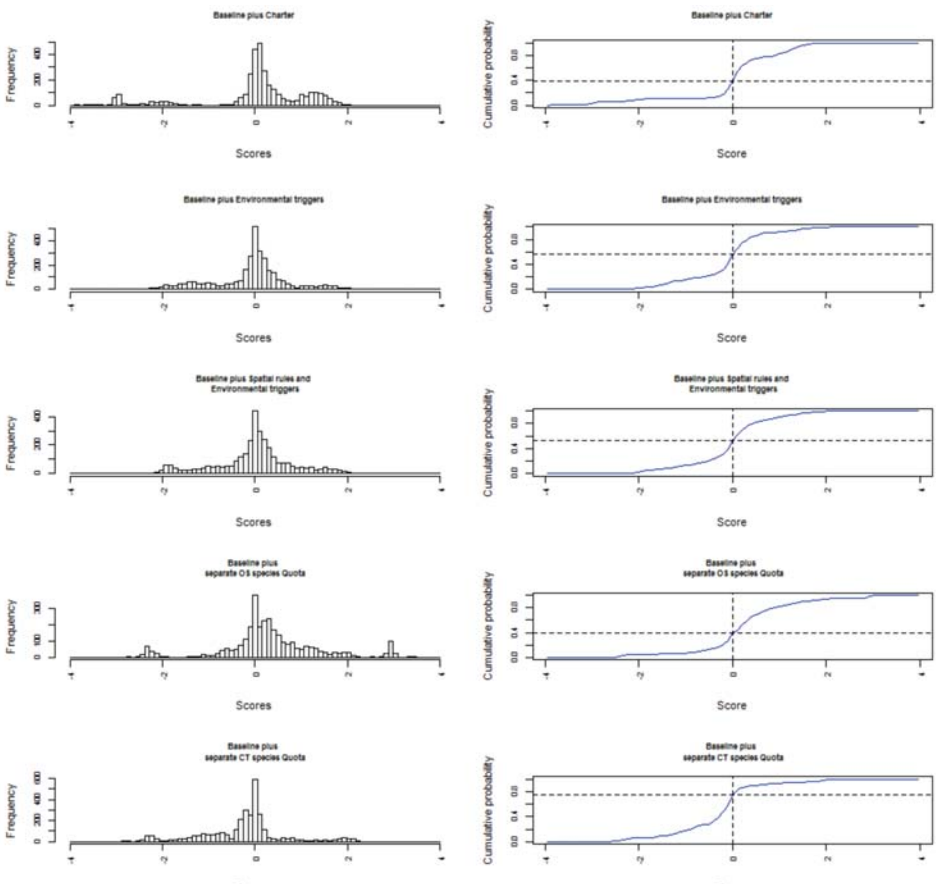

Figure 7. Weighted impact score distributions and their cumulative subjective probabilities.

The derived cumulative subjective probabilities in Figure 7 represent the likelihood that a harvest strategy alternative would perform better than the baseline harvest strategy alone. From these, it can be seen that no single alternative management option was considered an improvement in all cases, with both positive and negative outcomes expected given the variability in expected impact and objective weightings. The cumulative subjective probability associated with the point at which the score equals zero provides a measure of the relative likelihood of a positive or negative outcome. For example, based on the relative frequency of each score in the outcome set [59], the addition of a separate allocation to the charter sector is expected to have a 60% chance of a positive outcome and a 40% chance of a zero or negative outcome.

The results were also considered by stakeholder group to determine if there were substantial differences of opinion in terms of the relative merit of particular harvest strategy additions. The use of mean scores has been found to provide a more reliable indicator than individual scores in other studies where expert opinion has been elicited [61]. Given the common set of expert assessments of the impacts of each harvest strategy on the different objectives, differences between groups reflects the differences in the importance given to these objectives.

The average score for the charter allocation option was small but positive for all of the stakeholder groups (Table 3). Similarly, the average score for the split OS quota was also positive across all of the stakeholder groups. This suggests that, on average, these options would be beneficial from the perspective of all groups. In contrast, the split CT quota was negative for all groups, suggesting it is not a desirable option.

Table 3. Average weighted "score" by stakeholder group.

Stakeholder Group	Charter	Environmental Overrides	Spatially Explicit Control Rules and Environmental Overrides	Split OS Quota	Split CT Quota
Commercial fisher	0.06	−0.13	−0.06	0.28	−0.28
Charter boat operator	0.09	−0.02	0.07	0.37	−0.23
Recreational fisher	0.09	−0.07	0.02	0.34	−0.26
Quota owner	0.06	−0.15	−0.07	0.28	−0.29
Processor/wholesaler	0.09	−0.02	0.04	0.38	−0.24
Fishery manager	0.10	0.03	0.08	0.49	−0.23
Scientific advice	0.11	0.02	0.09	0.46	−0.22
Other	0.10	0.00	0.08	0.40	−0.24

The scores for environmental overrides were generally negative on average for the commercial and recreational sectors, but positive for the manager, scientist and other stakeholder groups (Table 3). Adding spatially explicit control rules improved the average score for all of the stakeholder groups, although the overall average was still marginally negative for quota holders and commercial fishers.

An alternative to considering the average score is to consider the proportion of outcomes with a negative score (Table 4). Generally, the charter allocation and split OS quota produced negative outcomes on fewer than 35% of cases, whereas the split CT option resulted in negative scores more than 57% of cases.

Table 4. Proportion of estimates with a negative value by stakeholder group.

Stakeholder Group	Charter	Environmental Overrides	Spatially Explicit Control Rules and Environmental Overrides	Split OS Quota	Split CT Quota
Commercial fisher	0.30	0.51	0.48	0.31	0.64
Charter boat operator	0.29	0.37	0.35	0.29	0.59
Recreational fisher	0.29	0.45	0.39	0.32	0.61
Quota owner	0.29	0.53	0.49	0.31	0.64
Processor/wholesaler	0.33	0.34	0.38	0.25	0.58
Fishery manager	0.35	0.33	0.32	0.27	0.59
Scientific/advice	0.31	0.36	0.34	0.25	0.57
Other	0.30	0.36	0.34	0.29	0.58

5. Discussion and Conclusions

The aim of the study was to identify the impact of different harvest strategies for the CRFFF in achieving ecological, economic and social objectives, as identified by the various stakeholder groups. A fourth objective was also considered, namely, the implications of the management option for fishery governance, following the proposal by Stephenson, et al. [3]. The process was undertaken with considerable stakeholder engagement, with the CRFFF Working Group developing the operational fishery objectives and also the baseline and potential alternative harvest strategies.

While the Working Group agreed on a set of objectives that the harvest strategy should address, not surprisingly the importance weight given to these objectives varied between stakeholder groups. All groups tended to rank the ecological sustainability objectives the highest. The relative weight of the economic objectives varied between stakeholder groups, with the commercially oriented groups (fishers, quota owners and buyers) generally weighting economic objectives similar to the ecological sustainability objectives, while the other groups tended to weight the economics objectives much lower. Social objectives were generally given a low weight by all stakeholder groups, with the exception of recreational fishers and the "other" group, which consisted predominantly of conservation group and industry association representatives.

These different objective weightings had an impact on how the different harvest strategy options were potentially perceived by the different stakeholder groups. For example, the use of environmental overrides was considered to result in benefits in terms of expected ecological outcomes but at a higher economic cost. For the commercially oriented groups with similar economic and ecological sustainability objective weights, these effects largely cancelled out, resulting in a slight negative expected benefit. For the other groups with the lower economic weighting, these options were seen to result in a positive outcome.

The apparent trade-offs between ecological and economic outcomes also reflects a tendency for most respondents to discount future economic and ecological impacts (both positive and negative) differently. For example, harvest strategies that performed well against the objective of achieving MEY-level stocks should also result in longer term economic benefits. However, the impacts estimated by the stakeholders were much more short term in respect to economic outcomes than ecological outcomes. This may reflect the state of economic resilience in the fishery, where a reduction in economic performance due to higher operating costs involved in achieving higher ecological performance may result in greater short-term economic stress. To some extent this is also reflected in the relative weighting by the groups, with those sectors with a financial stake in the industry placing greater importance on economic outcomes, potentially not so much to only improve economic performance, but to also ensure it does not deteriorate.

While we did not test every combination, the analyses demonstrate how triple bottom line outcomes can be affected by relatively small changes in the harvest strategy and through combining approaches targeted at particular aspects. For example, the addition of spatial consideration to the environmental override option was introduced to improve both ecological outcomes and social outcomes, with spatial management allowing inter-regional equity considerations to be addressed. Although social objectives had a low weighting for many groups, the additional social benefits from the introduction of spatial considerations were sufficient to change the sign on the average net score from negative to positive for some groups, and reduce the magnitude of the negative sign in the others.

The outcomes from the process are not necessarily an endpoint in terms of determining an optimal harvest strategy, since managers will need to consider these findings in light of the agreed strategic direction, their legislative mandate and feasibility. The perceived relative benefits of alternative harvest strategy options were opinion-based: harvest strategy evaluation against triple bottom line objectives, acknowledging alternative sector weightings, can also be undertaken quantitatively using simulation modelling. While acceptability to all groups may not be required given the constraints under which managers must operate and also the diversity of views across and within stakeholder groups, the process identified which areas of a potential option may need further consideration to be more acceptable to a greater proportion of stakeholders. For example, reducing the costs (or the perception of costs) associated with the environmental overrides and spatial management options would result in benefits being realized by all groups. Similarly, further investigation as to why separate OS quota was seen as desirable, while separate CT quota was not, may lead to improvements in the management of both sets of species. As a consequence, these results provide valuable insights which can inform the subsequent consultation to refine the harvest strategies. While considered separately, the options are not mutually exclusive. For example, a charter sector allocation could be implemented in addition to the other options.

A key feature of the process used in this study is that it allows managers to integrate all dimensions of sustainability into the harvest strategy development process and also provides an explicit role for stakeholder engagement. Industry and other groups were directly involved in identifying the objectives, weighting the objectives, identifying the potential harvest strategies and providing input (based on expert knowledge) as to how these strategies are likely to perform. The process provides a formal framework in which this consultation can take place. As such, it directly addresses the key impediments to developing effective EBFM [3] by providing a suite of stakeholder-developed ecological, economic, and social objectives as well as a general process to integrate these into harvest strategies that consider the three dimensions of sustainability.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/11/3/644/s1: Detailed description of the alternative harvest strategies.

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Determinants of Catch Sales in Ghanaian Artisanal Fisheries

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Abstract: The study examined the determinants of catch sales of artisanal fishers through wealthy middle women in fishing communities of Ghana, often known as *fish mothers* or "fish mongers". The effects of selected variables were examined with a double hurdle model. Self-financing was found to negatively affect the fishers' sale of fish catch through *fish mothers*. The fishers were 19% less likely to sell to *fish mothers* if they self-finance, and that self-financing will result in a 10% downward unconditional change on the percentage of fish sold to the *fish mothers*. Factors that positively influenced the sale of fish catch through the *fish mothers* were price, percentage of high value fishes, size of boat, fishing experience, and number of fishing trips conducted in a year. The estimated average partial effects of boat size had the strongest effect with about 146% and 91% change, respectively on conditional and unconditional effect on the percentage of catch sales sold through the *fish mothers*. Overall, the study shows that long-term consistent economic and investment considerations such as investing in larger boats are important drivers for fishers' choice of selling catches through fish mothers. The main implication of the results is that fishers need some economic leverage such as access to formal capital and financial resources to incentivize them to exercise control over their marketing activities so that they can receive a higher profit from their fishing operations. This is important for the sustainability of coastal fisheries communities and the sector as a whole. Artisanal fishers need resources such as low interest loans and market information systems that will enable them to negotiate prices for their fish catch with fish mothers.

Keywords: artisanal fishers; double-hurdle; fish marketing; *fish mothers*

1. Introduction

Ghana is an advanced fishing country relative to other African countries with very experienced fishers, which has been attributed to long traditions from the colonial era. Marine fishing in Ghana was developed mainly with the arrival of European traders when the Europeans hired fishers as canoe men to transport people and goods from their ships to the beaches, and vice-versa [1]. The marine capture fishery in Ghana is the major source of local fish production, accounting for over 80% of the total fish product supply [2]. The sector consists of four subsectors: small scale or artisanal, semi-industrial or inshore, industrial or deep sea, and tuna fleets. The fishing sector plays a major role in poverty reduction and livelihoods for coastal communities, which is estimated to contribute about 1.2 percent of Ghana's gross domestic product (GDP) and 5.6 percent of the Agriculture GDP [2,3]. The low national GDP contribution from the fisheries sector is due to declining fisheries stocks [3]. The small scale or artisanal subsector accounts for about half of the total marine catch in Ghana [2,4], which makes it important for the sustainability of the fisheries sector.

The artisanal fishery involves the use of canoes or dug-out wooden boats with inboard or outboard engines. The fishing gears are diverse, including beach seine nets, purse seine nets, set nets, drift gillnets, and hook and line. The major commercial species landed are small pelagic low value fishes such as anchovies (*Engraulis* spp.), sardinellas (*Sardinella* spp.), and mackerels (*Scomber* spp.). Large motorized canoes or boats operate in deep waters and have storage facilities or compartments on board for storing ice to preserve catches. The main fishes landed by artisanal fishers include sardinellas (mainly *Sardinella aurita*), tuna (*Auxis thazard*), mackerels (mainly *Scomber japonicas*), burrito (*Brachydeuterus auritus*), and Atlantic bumper (*Chloroscombrus chrysurus*). Some of the minor fishes landed include red fish (mainly *Sparus caeruleostictus* and *Dentex angolensis*), anchovies (*Engraulis encrasicolus*), flat fish species, and the white grouper (*Epinephelus aeneus*), some of which are considered high value fishes. Most of the fishers target high value species such as white grouper, tuna, and red fish because of the high demand and premium prices, however the percentage of these fishes landed are low due to the fishing methods used and unhealthy fish stocks [5,6].

The artisanal fishery plays an important role in coastal communities by providing employment, income, and a cheap source of protein. The major challenges they face are seasonality, small margins and low returns [5,7,8]. The sector's performance is critical for the growth, economic development, and sustainability of the coastal communities. The returns accruing to artisanal fisheries are affected by several factors including limited value addition and consequent post-harvest losses, weak backward-forward market linkages, poor infrastructure, low bargaining power, as well as low and lack of variety of catch. Expenses associated with fishing activities include fuel, food, labor, taxes, and other variable overheads.

Women are important players in the small-scale fisheries subsector in developing countries. Their participation rate in pre- and post-harvesting activities is estimated at about 48%, and in Ghana, it is around 40% [9]. Women participation in the subsector is higher if only post-harvest is considered. In particular, women in Ghana have a vital role in informal financing of fishing operations [7,10], partly due to lack of access to financial support from other channels like bank loans.

The marketing system and remuneration for the artisanal fishery take a number of forms. A proportion of the catch goes to wealthy middle-women, often known as "*fish mothers*" or "*fish mongers*" to cover any pre-financing arrangements; a portion is sold or given to the boat owner to cover fixed costs (boat and fishing gear); hired laborers may receive a portion of the catch as wages; and smaller portions are shared [10]. Thus, fish may be sold through *fish mothers* as well as other female fish value chain agents including fish processors, fish retailers, food vendors, relatives, and spouses. Some spouses may also be *fish mothers*. Fishing is a capital-intensive industry, and an advantage to fishers for selling their catch to *fish mothers* is the reciprocal leverage they have to secure relatively low cost capital to finance their business like fuel cost. Selling fish catch to *fish mothers* has less risk as it is a cash market, and usually *fish mothers* can buy high volumes of fish landed. Fishers can obtain higher prices especially from *fish mothers* who primarily serve distant regional, or national, and in some cases international markets [7]. However, there are some disadvantages for selling to *fish mothers*. *Fish mothers* have often used their financing leverage to acquire and own fishing equipment used by the fishers and therefore control the production chain [10].

The traditional roles for women in the fishing industry in Ghana, which were structured through responsibilities and customary roles for accessing resources are gradually changing [10]. Traditionally, a fisher is required to provide fresh fish from his catch to his spouse for retailing either as fresh or processed products to generate income to maintain the household as well as to provide income for further investments in the fishing business. However, there are increasing capital costs associated with artisanal fisheries due to the use of larger canoes, high powered motors, and expensive fishing equipment, and limited access to formal bank credit because of a low loan repayment rate arising from poor loan management, low catches, high risks of industry participation, and relatively high indebtedness of fishers [11]. Therefore, it appears fishers are increasingly taking control of their earnings to ensure capital is available to invest in the fishing business, thus taking away the traditional fish marketing role from their spouses [7,10].

Artisanal fishers carry out their transactions through various marketing channels including middle-women, spouses, processors, small traders, food vendors, and direct to end users. Each channel provides some level of benefits and returns. *Fish mothers* tend to pre-finance fishing trips of fishers who need credit with fuel and food in exchange for secure access to the catch from the fishers. In the artisanal fishery value chain in Ghana, it is commonly perceived that *fish mothers* and processors accrue a greater percentage of the profit margins generated along the fisheries value chain, followed by retail traders, and then the fishers. The literature on food and product markets in developing countries has overwhelmingly reported increasing power of middlemen, intermediaries and retailers, and their tendency to negotiate lower prices from producers [12–14]. *Fish mothers* usually trade diverse food products, which gives them more access to capital, providing them some leverage with both fishers, processors and retail traders [10]. *Fish mothers* can pre-finance several fishers and consequently have access to ample supply of fish. Such arrangements tend to place some power in the hands of the *fish mothers* at various landing sites [7,10].

The motivation for and determinants of fishers' choices and decisions regarding who to sell fish have not been empirically tested, though commonly, *fish mothers* are the preferred choice for selling fish catch. This study seeks to fill that information gap by examining the relationship between the fishers' decisions to sell fish catch and the percentage of catch sold through *fish mothers* and a number of economic and socio-demographic factors. Since *fish mothers* commonly pre-finance fishing trips of some fishers in the form of fuel and food, which in turn force the fishers to sell through *fish mothers*, the main hypothesis examined in this study is whether fishers' self-financing affects the decision to sell through *fish mothers* and the actual percentage of catch sales through them. Other factors examined include input characteristics such as boat size, number of fishing trips per year, as well as some demographic characteristics.

2. Modeling Framework and Empirical Specifications

The Double Hurdle (DH) model [15–17] is adopted to examine the fisher's marketing decision to sell fish catch through *fish mothers*. The decision process is assumed to involve two hurdles: the first hurdle relates to whether or not the fisher will sell their catch to *fish mothers* (y^*_{1i}), and the second relates to the percentage of fish catch sold through *fish mothers* (y^*_{2i}). The hurdles involve zeros because some fishers do not sell fish catch through *fish mothers* at all. The DH model addresses the zero outcomes arising from the fishers' deliberate decisions, and it is a more general and flexible model than other models such as the Tobit model [18] by allowing separate stochastic processes for the incidence and intensity of sales [19]. The DH model is commonly applied to market participation studies [17,20–25].

The DH model allows the decision to sell to *fish mothers* and the percentage of sales to be determined by two different stochastic processes. Thus, the model permits the possibility of estimating the first and the second decision processes using a different set of explanatory variables.

In the first hurdle, the latent variable underlying the fisher's decision to sell to *fish mothers* is represented as a binary process:

$$y^*_{1i} = \gamma'_1 \boldsymbol{X}_{1i} + \pi_i \qquad \pi_i \sim N(0,1) \tag{1}$$

where $\boldsymbol{X}_{1i}$ is a vector of explanatory variables, and π_i is the error term. The observed decision of the fisher is then modeled as:

$$y_{1i} = \begin{cases} 1 \text{ if } y^*_{1i} > 0 \\ 0 \text{ otherwise} \end{cases} \tag{2}$$

In the second hurdle, the latent variable describing the percentage of fish catch sold to *fish mothers* is represented as:

$$y^*_{2i} = \gamma'_2 \boldsymbol{X}_{2i} + \vartheta_i \qquad \vartheta_i \sim N\left(0, \sigma^2\right) \tag{3}$$

where ϑ_i is the error term, and the observed percentages is represented as:

$$y_i = \begin{cases} \gamma_2' X_{2i} + \vartheta_i & \text{if } y_{1i}^* > 0 \text{ and } y_{2i}^* > 0 \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

and the Υs are coefficients to be estimated.

Given the cross-sectional nature of the data, the DH model is estimated using maximum likelihood estimation procedures and tested for potential presence of heteroscedasticity using a chi-squared test. If there is heteroscedasticity, the model estimates will be inconsistent. Consequently, the variance of the error term in Equation (4), σ^2 is allowed to vary across observations. The standard deviation σ_i is specified as:

$$\sigma_i = \sigma \, . \, \exp(\delta' \mathbf{h_{2i}}) \quad (5)$$

where $\mathbf{h_{2i}}$ is a vector of select continuous variables included in X_{2i}, and δ is a vector of coefficients [22]. If the model is homoscedastic, $\delta = 0$. The specification in Equation (5) ensures that the standard deviation is strictly positive [24,25].

The DH models outlined above with and without specification adjustments for heteroscedasticity were estimated for fishers' decisions to sell fish catch through *fish mothers* using the LIMDEP software version 10.0.

The data used in the study was collected in the summer of 2013 from artisanal fishers at major coastal fishing communities in Ghana, i.e., Chorkor, Jamestown, and Tema in the Greater Accra region, and Elmina, Cape Coast, and Moree in the Central region. The semi-structured questionnaire solicited information on the major activities and services of fishers, costs and revenues associated with their activities, fish landed, prices, business transaction methods, marketing channels, fishing gear used, and demographic factors. The subjects were selected randomly and surveyed at each fishing community.

3. Data

Data was collected from 202 artisanal fishers but only 96 responses were used in this analysis because they corresponded to the full responses provided for the relevant variables needed for the analysis. Information on the method of transaction was also collected, and whether they self-financed fishing operations. Information on the percentage of fish sold through *fish mothers* or other marketing outlets was also collected. Other outlets consist of mainly spouse and relatives, and direct to consumers. *Fish mothers* generally operate as wholesalers [10]. Other information includes the size of fishing boat.

The variables used in the estimation process are reported in Table 1. The proportion of artisanal fishers selling to *fish mothers* is about 77%, and on average, about 73% of their fish catch was sold through *fish mothers*. Fish prices generally varied with season and fish species. There are two major fishing seasons in Ghana: the major upwelling or bumper season, which is usually from the end of June or early July through late September or early October, and the minor upwelling season, which occurs from late December or early January through February [26]. Respondents reported the composition of fish landed in the past three fishing seasons. They also reported the prices received for the various species in both the major and minor seasons. The price of the fish landed depended on demand and supply, costs, and grade. A weighted average price was therefore calculated for the analysis based on the season and value of fish. Table 1 shows that prices on average ranging from \$1.50/kg to \$22.5/kg.

Table 1. Description and Summary Statistics of Variables.

Variable	Sample Statistics (n = 96)		
	Mean	Min	Max
Dep. Var. Hurdle 1: Sold to *fish mothers* (=1)	0.77	0	1
Dep. Var. Hurdle 2: Percentage fish catch sold through *fish mothers* (%)	72.83	0	100
Explanatory Variables:			
Weighted average price of all fishes (US$/kg)	4.10	1.5	22.6
Percentage of high value fish landed (%)	25.00	0	100
Self-financing for fishing activities (=1)	0.55	0	1
Boat size (meters)	16.41	8.0	27.0
Experience (number of years fishing)	19	3	41
Number of fishing trips in a year	243	12	317
At least a primary education (=1)	0.87	0	1
Located in Greater Accra (=1)	0.78	0	1

Based on multiple responses, 30.6% of fishers reported landing *Sardinella* spp., 16.1% tuna, 15.4% mackerels, 13.5% burrito, 12.3% Atlantic bumper, 5.6% red fish, 2.7% anchovies, 2.5% *Soleidae* spp., and 1.2% white grouper. The FAO [2] also reported that sardines and mackerel are among the commonly landed fish species in Ghana, and constitute the most commercially important coastal fisheries. The fishers reported low landing of shrimps (mainly *Parapenaeopsis atlantica* and *Penaeus kerathurusthat*), Atlantic bigeye (*Priacanthus arenathus*), European barracuda (*Sphyraena sphyraena*), Trigger fish (*Balistes punctatus/capriscus*), and Bigeye Scad (*Selar crumenophthalmus*). White grouper, tuna, and red fish are considered high value fish.

Most of the fishers have at least a primary education (87%), and the average fishing experience was 19 years. Over half (55%) of the fishers were self-financing their fishing operations. Fishers used a range of canoe (boat) sizes varying from 8 m to 27 m, with an average of 16.4 m. The average number of trips per year ranged from 12 to as many as 317.

4. Results and Discussion

A chi-square test statistically rejected the homoscedastic model in favor of the heteroscedastic model with an alternative variance specification (Table 2). Tables 3 and 4 present the maximum likelihood estimates for the homoscedastic and heteroscedastic models respectively. To assess the total impact of the explanatory variables on fishers' decisions, the Average Partial Effects (APEs) from the heteroscedastic model are discussed (Table 5). The APEs are evaluated at the means of each variable. They are decomposed into three components, i.e., the effect on the probability of selling fish catch to *fish mothers* (Prob $[y > 0]$), the effect on the unconditional expected value of percentage fish sold to the *fish mothers* ($E[y]$), and the effect on expected value of percentage fish sold to the *fish mothers* conditional on positive expected value ($E[y \mid y > 0]$).

Table 2. Likelihood ratio tests of homoscedasticity restriction.

	Estimate
Homoscedastic Model	LLF = −52.521
Heteroscedastic Model	LLF = −33.808
χ^2 test statistic	37.426
χ^2 (1,0.01) critical value	6.63

Table 3. Estimated parameters from homoscedastic double-hurdle model [a].

Variable	Hurdle 1: If Sold to *Fish Mothers*	Hurdle 2: % Sold through *Fish Mothers*
	Coefficient (γ_1)	Coefficient (γ_2)
Weighted average price of all fishes (US$)		0.021 ** (0.014)
Percentage of high value fish landed (%)		0.004 *** (0.001)
Self-financing for fishing activities (=1)	−0.652 ** (0.036)	−0.058 (0.445)
Boat size (meters)	0.367 ** (0.027)	0.871 *** (0.000)
Experience (years)		0.197 *** (0.000)
Number of fishing trips in a year		0.229 (0.195)
At least a primary education (=1)	0.142 (0.773)	0.164 (0.168)
Located in Greater Accra (=1)		0.035 (0.708)

[a] *p*-values are given in parentheses; *** and ** represent significance at α = 0.01 and α = 0.05 respectively.

Table 4. Estimated parameters from heteroscedastic double-hurdle model [a].

Variable	Hurdle 1: If Sold to *Fish Mothers*	Hurdle 2: % Sold to *Fish Mothers*	Heterogeneous Equation
	Coeff. (γ_1)	Coeff. (γ_2)	Coeff. (δ)
Weighted average price of all fishes (US$)		0.015 *** (0.001)	
Percentage of high value fish landed (%)		0.002 * (0.051)	
Self-financing for fishing activities (=1)	−0.676 ** (0.033)	0.050 (0.333)	
Boat size (meters)	0.320 *** (0.009)	1.211 *** (0.000)	−2.913 *** (0.001)
Experience (years)		0.105 *** (0.002)	
Number of fishing trips in a year		0.107 *** (0.000)	
At least a primary education (=1)		0.022 (0.780)	
Located in Greater Accra (=1)	0.351 (0.337)	0.012 (0.836)	

[a] *p*-values are given in parentheses; ***, **, and * represent significance at α = 0.01, α = 0.05, and α = 0.10 respectively.

Table 5. Estimated average partial effects (APE) from heteroscedastic double-hurdle model.

Variable	Prob[y > 0]	E[y]	E[y | y > 0]
	Coeff.	Coeff.	Coeff.
Weighted average price of all fishes (US$)	0.004 *** [b]	0.001 ***	0.001 ***
Percentage of high value fish landed (%)	0.000	0.000	0.000
Self-financing for fishing activities (=1)	−0.190 **	−0.102 **	0.012 **
Boat size (meters)	0.094 ***	1.461 ***	0.913 ***
Experience (years)	0.025 *** [b]	0.008 ***	0.005 ***
Number of fishing trips in a year	0.026 *** [b]	0.008 ***	0.005 ***
At least a primary education (=1)	0.005 [b]	0.002	0.001
Located in Greater Accra (=1)	0.100	0.056	0.005

***, **, and * represent significance at α = 0.01, α = 0.05, and α = 0.10 respectively; [b] parameter × 10^3.

The choice of explanatory variables included in the two hurdles is based on some economic theory and reasoning. Fishers are considered as rational businessmen and to take decisions to maximize their economic returns. In the literature, the first hurdle, which is based on the discrete choice preference theory, is often specified as a function of non-economic factors because the theory assumes that sample selection is determined by non-economic factors such as demographic characteristics [22,23]. In Table 4, price, percentage of high value fish landed, and some characteristics such as boat size, number of fishing trips per year as well as experience (measured as number of years of fishing) have a positive and significant effect. The APEs reported in Table 5 are positive and significant as well, which indicates the positive responsiveness of fish sold to *fish mothers* to changes in these factors. Self-financing of fishing trips is found to negatively impact fish sold to *fish mothers*.

Self-financing fishing trips relative to other forms of financing fishing activities negatively impacts the decision to sell to *fish mothers* (Table 4). The magnitude of the estimated APEs (Table 5) suggests that it is important and that fishers are 19.0% less likely to sell to *fish mothers* if they self-finance their fishing operations. Also, self-financing will result in a 10.2% downward change on the unconditional percentage of fish sold to the *fish mothers*. As indicated earlier, some *fish mothers* pre-finance fishing trips of fishers to secure access to their catch. Consequently, self-financed fishers are not obligated to sell their fish through the *fish mothers*. Such fishers may be mindful of their economic portfolio and the flow back of resources to the household. They could probably sell through their spouses or relatives [10,27]. However, conditional on a positive decision to sell fish to the *fish mothers*, self-financing will result in just a 1.2% upward change in the percentage of fish catch sold.

From Tables 4 and 5, the positive effect of price, though relatively small is perhaps due to the ability of fishers to negotiate prices with the *fish mothers*. The change in price on both conditional and unconditional sale of fish catch to *fish mothers* is about 0.1% *ceteris paribus*, i.e., all else unchanged (Table 5). Traditionally, fish landed are priced by the *Fish Queen*, the Head of *fish mothers* in consultation with the Chief fisher [7,10,27]. However, some fishing communities have invested in improved landing facilities, and charge landing fees, which then allows the fishers to negotiate prices on individual basis with the *fish mothers* [7]. In addition, *fish mothers* buying fish to sell in markets with better prices may offer fishers more competitive prices. A similar interpretation could apply to the positive impact of high value fishes. Low value fish such as *Sardinellas* are often in commercial abundance, which impacts its value. To prevent waste, *Sardinellas* tend to be preserved through smoking or drying. However, the percentage catches of high value fishes such as red fish (*Dentex* spp.) are relatively low (25% in Table 1) and they are sold fresh. *Fish mothers* would likely offer higher prices due to the high demand and high profit.

The size of boat is found to be a significant variable and positively impact the probability of selling to *fish mothers* and the percentage of fish sold to them (Table 4). The magnitude of the estimated coefficient (0.32 in Hurdle 1 and 1.21 in Hurdle 2—Table 4) is the strongest compared to the other variables. The change in boat size on both conditional and unconditional sale of fish catch to *fish mothers* is about 146% and 91%, respectively (Table 5) suggesting a very strong effect. Larger boats operate in a wider area, from near landing sites to relatively more open waters, and as such exploit more catches compared to smaller boats [28]. Larger boats can also handle and store fish in good condition on board as they are motorized, and most are equipped with hydraulic hauling machinery, fish-finding electronics, ice, and storage facilities, which improves the efficiency of fishing and handling of fish [29]. Perhaps, the strong impact of having larger boats on fish sold through *fish mothers* results from higher fish catches and requires a higher purchasing power to absorb all the fish caught.

Regarding fishers' experience, a one-year change in fishing experience on both conditional and unconditional probability of sale of fish catch to *fish mothers* is about 0.8% and 0.5%, respectively (Table 5). Similar probabilities are found for the number of fishing trips taken in a year (Table 5). Though the experience variable has a relatively small effect, it is likely that experienced fishers have better understanding of fish movements, and consequently better fish catch. Also, experienced fishers may have a better knowledge of the fish markets and social connections that could make them to sell to *fish mothers*. Knowledge gained from fishing experience is reported to influence relocation of fishers along the west coast of Africa [30] and loan repayments by fishers [11]. Regarding the number of trips, the probabilities imply that the higher the number of trips, the higher the effect on fish sold to the *fish mothers* as a more consistent relationship was set up.

5. Conclusions

This study assessed the determinants of marketing decisions of artisanal fishers regarding the fish catch sold through *fish mothers*. The empirical model was a double-hurdle that addressed the zero outcomes arising from the fishers' deliberate decisions not to sell through *fish mothers*.

Self-financing of fishing trips was found to negatively impact fish sold to *fish mothers*. It is the only variable that has a negative impact. The magnitude of the estimated coefficients suggests that self-financing has a strong effect, i.e., fishers were 19% less likely to sell to *fish mothers* if they self-finance their fishing activities as they will receive higher prices without the binding agreements with the *fish mothers*, and that self-financing will result in a 10% downward change on the unconditional percentage fish sold to the *fish mothers*. Such fishers would probably sell through their spouses or family relatives.

The impact of price, percentage of high value fish landed, boat size, number of fishing trips per year as well as fishing experience were found to have a positive and significant effect on the percentage of fish sold through *fish mothers*. The estimated average partial effects suggest that boat size had the strongest effect on fish sold through the *fish mothers*, with about 146% and 91% change, respectively on conditional and unconditional sale of fish catch, which is likely caused by higher catches. But price, percentage of high value fish landed, the number of fishing trips per year and fishing experience had relatively smaller effects.

Overall, the study shows that long-term consistent economic and investment considerations such as investing in larger boats are important drivers for fishers' choice of selling catches through *fish mothers*. Larger boats operate in wider and deep waters and have higher hauling capacity and as such exploit more catches. The main implication of the results is that fishers need some economic leverage such as access to formal capital and financial resources to incentivize them to exercise control over their marketing activities so that they can receive a higher profit from their fishing operations. This is important for the sustainability of coastal fisheries communities and the sector as a whole. Artisanal fishers need resources such as low interest loans and market information systems that will enable them to negotiate prices for their fish catch with *fish mothers*.

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Estimating the Public's Preferences for Sustainable Aquaculture: A Country Comparison

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Abstract: Integrated Multi-Trophic Aquaculture (IMTA) is an alternative to the monoculture of fin fish species, in which several species are combined in the production process. This can have environmental advantages such as a lower environmental impact through nutrient cycling and natural filters; and can have economic advantages consisting of increased efficiency, product diversification and potential price premiums. In this paper, a choice experiment (CE) was conducted through an online survey in Ireland, the UK, Italy, Israel and Norway, to assess how the public makes decisions on what type of salmon or sea bream to buy based on the attributes of the product. Analysis assessed the Willingness-to-Pay (WTP) for more sustainable produced seafood using a Latent Class multinomial logit modelling approach. In the experiment, an ecolabel was used to distinguish between regularly produced (monoculture) products and sustainably produced (IMTA) products. The general public in each country showed a positive attitude towards the development of such an ecolabel and towards the payment of a price premium for the more sustainably produced salmon or sea bream.

Keywords: aquaculture; IMTA; ecolabel; choice experiments; latent class; WTP

1. Introduction

Seafood production is increasingly challenged in the context of human population growth, increasing global per capita seafood demand and diminishing wild fish stocks [1–3]. Aquaculture is viewed by many as an alternative to wild fisheries and in recent years the aquaculture industry has shown considerable growth. However, in 2014 the annual European aquaculture industry increased by 0.5 percent against a growth of 7 percent globally [4]. Due to the international character of the seafood market, the EU is currently looking into the marketing of the seafood industry at the transnational level through educating the public and stimulating producers to shift towards sustainable production methods. One of the proposed strategies is the use of an ecolabel for seafood products that indicates the degree of sustainability of the production of the seafood product [5].

Integrated Multi-Trophic Aquaculture (IMTA) has also been proposed by academics and policy and industry actors to reach the dual aim of economic growth and environmental sustainability [6–8]. Multiple experiments have been conducted with IMTA; in the Far East, aquatic species have traditionally been co-cultured for centuries and in recent years IMTA has been implemented experimentally in modern industrial forms in Canada [9], Israel [10] and the Netherlands [11]. However, despite this call for IMTA integration in the European industry, IMTA has not been adopted on an industrial scale. In an IMTA system, multiple species from different trophic levels are combined in the production process. The species are selected based on their function in the ecosystem and economic value. Combining them has the advantage of allowing for nutrient cycling in the production process.

On the one hand, this allows for environmental benefits, as the added species extract organic and inorganic wastes that would otherwise be discarded from the fed finfish cages [12–15]. Additionally, bivalves consume sea lice copepods [16], the main parasitic infection contributed to intensive salmon farming [17]. The inclusion of bivalves in an aquaculture production system could contribute to the mitigation of such parasites thereby limiting the environmental impact of the farm. On the other hand, IMTA has potential economic benefits, as nutrient cycling may reduce feed costs per unit biomass. Some research results suggest that IMTA systems may have higher growth rates for the lower trophic species [15].

In addition, products from an IMTA system can produce higher profits than monoculture products as the public may have willingness-to-pay (WTP) for products from an IMTA farm as opposed to a monoculture farm. Research has indicated that the public indeed values an IMTA approach to fish farming [18–21]. A small-scale study in New York concluded that IMTA produce outperformed monoculture salmon on the main seafood purchase determinants of product quality, freshness and taste [18]. Regarding the public's preferences for IMTA produce, several studies identified a positive WTP for salmon produced in an environmentally friendly manner in Scotland [21], the US Pacific Northwest [19] and Canada [20]. Higher marginal WTP should translate to additional revenue, which could function to cover potentially additional costs to IMTA production practices, particularly in the short run, as opposed to monoculture production [12,15,22].

However, an essential element in the valuation of IMTA products is the public's ability to distinguish between monoculture and IMTA products [18,23]. Both industry and non-industry actors have proposed eco-labelling to create bottom up pressure to reform production systems to prevent the over-exploitation of natural stocks [24]. Eco-labelling is an increasingly used tool that can change purchasing behaviour by educating the public on the environmental impact of purchasing decisions. Eco-labelled seafood has been found to be preferred over unlabelled seafood in several studies [24–31]. Despite aquaculture products being perceived distinctly different from wild-caught products [28], according to our knowledge, research on preferences specifically for aquaculture ecolabels is limited to Roheim [28] and Yip et al. [19]. Individuals prefer wild products over farmed products, even when these farmed products are certified [28]. Yet within the aquaculture market, products produced in CC (Closed Containment) and IMTA systems are preferred over monoculture production, with strongest preferences expressed for IMTA [19]. Further research on public preferences for aquaculture labelling and production methods is essential if environmental labelling is to be used as a tool to internalize any external costs from the aquaculture industry.

In this paper, we explore the market potential of IMTA across five countries, Ireland, UK, Norway, Italy and Israel, by estimating the public's preferences for the products of sustainable aquaculture. Specifically, we answer the question: is the public willing to pay a price premium for fish cultured sustainably in European and Israeli farms? If so, then part of the European marketing strategy [5] should include the promotion of the sustainability and production location attributes. In this study, preferences are elicited using a choice experiment (CE) that asked respondents from the five countries to choose from among fish with different levels of sustainability, different locations of production and different prices. The WTP for the sustainability and location attributes was estimated based on the choices. The CE approach was taken due to its capacity to capture diversity among the countries and to enable a cross-country comparison. This adds to the current dearth of multinational research on preferences for IMTA.

Current aquaculture growth is taking place in a context of rising awareness and public concern over food production, specifically on issues such as food safety, food quality, health impacts, environmental sustainability and animal welfare [32]. Against this background, several seafood consumer awareness ecolabels have been developed such as the Earth Island Institute's Dolphin Safe label and Marine Stewardship Council (MSC) labels. Ecolabels consist of a physical label on a product, indicating that it fulfils the criteria defined for sustainable production, thus communicating the environmental effect of production of the good [3]. This differentiates eco-labelled seafood products from unlabelled products, with the aim of stimulating environmentally friendly purchasing behaviour in order to increase demand for certified products, hence decreasing the environmental impact of the fast-growing industry [33].

The economic impact of eco-labelling is influenced by several factors. First, it depends on the degree of one's altruism [34]. Individuals weigh their utility for attributes related to self-interest, such as health, to their utility for attributes outside of their individual interest, such as sustainability [29]. Second, WTP is influenced by an individuals' income. As individuals with a high income have a lower marginal utility for income [35], their price sensitivity will be low and their WTP will be higher [29]. This implies that in the creation of the model and interpretation of model results, the income level of respondents must be taken into consideration to account for the difference in price sensitivity. Third, information plays a role in the value individuals attribute to a sustainability ecolabel. Individuals are more likely to use eco-labelled products when they have a higher degree of environmental awareness, are concerned about the environment and feel a responsibility towards contributing to its maintenance [36]. Lastly, one's WTP for a seafood product with a sustainability ecolabel is influenced by the perception of the product. Individuals will weight a product with their preferred level of sustainability against other products and attributes such as quality and value for money [37]. This has been accounted for in the experiment design deployed in this paper by including an opt-out option in every choice card.

2. Materials and Methods

2.1. Sample, Questionnaire and Data

Data was retrieved by ICM Research, an independent survey firm in the UK, who distributed the survey online among a population of randomly selected contracted clients. After selection, this sample was stratified according to the proportions of age, sex and region in each country, to ensure a representative sample. A sample of 2520 surveys was collected from five countries; Ireland (n = 500), Israel (n = 500), Italy (n = 508), Norway (n = 501) and the United Kingdom (n = 511). The countries were selected based on their geographical location and the characteristics of their aquaculture industries, aiming to include countries with both Atlantic and Mediterranean production sites. In the Atlantic area, the countries selected were Ireland, the UK and Norway. Ireland and the UK were selected as aquaculture production countries, with Ireland being characterized by its focus on the niche market of organic salmon aquaculture. Norway is included as European but non-EU member state that is characterized by its intensive large-scale salmon production. Outside of the Atlantic area, Italy and Israel were chosen as key sea bream farming countries operating in the Mediterranean area.

Respondents to the survey were all in the market as potential fish consumers. The choice experiment was part of a broader survey. Respondents were first told what the survey was about and given background information on what IMTA was and how it operated. It is recognized that providing respondents information about IMTA before the choice experiment can alter the expressed preferences. However, considering the lack of familiarity of respondents with IMTA, the CE could not be conducted without a basic understanding of the production method to allow a well-informed decision for every choice card presented. The survey consisted of four parts. The first part asked respondents about their perception of the aquaculture industry and marine environmental problems, followed by a section on seafood consuming behavior, focusing on respondents' use of ecolabels to make informed purchasing decisions. In the third part, respondents were presented with the choice experiment. In the final part respondents were asked about their socio-demographic indicators.

2.2. The Choice Experiment Methodology

The choice experiment (CE) method is a stated preference approach widely used to estimate the public's preferences and willingness to pay (WTP) for changes in environmental quality or new products. Choice experiments consist of a set of choice cards, each containing a set of alternatives from which respondents select their most preferred alternative. Each alternative consists of a combination of attributes that vary on attribute levels. In making their choices, respondents have to weigh the utility they derive from the different combination of attribute levels presented in each alternative. The assumption underlying this method is that respondents make fully rational decisions and therefore maximise their utility in every choice [38].

Choice cards often include two elements that assist the modelling process. A baseline alternative that reflects the status quo is often included in the choice cards. The inclusion of this alternative is necessary to mimic actual purchasing decisions when a new product enters the market; a consumer can choose to opt-out of a purchase altogether. This allows the statistical models to generate more welfare-consistent estimates [39]. The choice alternatives also include a monetary attribute. This allows the elicitation of an implicit price for each parameter, which reflects the respondents' WTP for a relative change in the attribute, given the changes in the other attributes [40]. The status quo alternative is always associated with a zero prize as no product is purchased in that decision. The aim of the choice experiment is to derive marginal values for attribute levels from the respondents' choices.

The choice experiment in this paper was designed to assess the public's marginal WTP for the attributes associated with IMTA products. In the choice experiment, respondents were presented with eight choice cards each, with each choice card consisting of three alternatives; two purchasing options and one opt-out option (no purchase). An example of a choice card for Ireland is given in Appendix A. The purchasing options were presented as a fillet of salmon for the Northern Atlantic countries and Sea Bream for the Mediterranean countries, as those are the main farmed species in each region. Respondents were first asked to "imagine that you walk into a supermarket and fresh (unfrozen) salmon [sea bream] is on your shopping list. The supermarket has several types of salmon [sea bream]. The packs are identical in size and quality, but some salmon [sea bream] is produced locally, some is produced abroad, and some is produced in a way that is better for the environment. They also vary in price. You are asked to indicate which of the salmon [sea bream] presented you would buy".

Respondents were then told what attributes they would have information on in the choice situation and to consider what they could afford to pay given their groceries budget. The attributes and attribute levels are described in Table 1. A pilot study conducted to determine the main attributes to present for seafood products found that a production location indicator was important in several sample countries. Literature suggests that consumers prefer locally produced food over imported produce [41,42] and that consumers' WTP for sustainability is partially influenced by attitudes towards other labels present in the market [43]. The experiment therefore includes production location as an attribute.

The sustainability attribute reflects the change in environmental pressure due to a change to an IMTA production system. Research has indicated that consumers have a WTP for sustainability in seafood, suggesting that production method should be included in the CE design [28]. Previous studies estimating WTP for specific production methods included an ecolabel reflecting the production system [19]. However, we decided against this approach for two reasons. First, the change in environmental pressure due to a shift to an IMTA production system can vary greatly, depending on species selection and the amount of the extractive species added to the production process, but also on environmental conditions, such as strength and direction of water currents [20,22]. A singular ecolabel would not confer such variations to individuals and therefore not inform individuals on environmental effects. Second, a common critique towards ecolabels is their dichotomous nature, which does not contribute to informing the public on the environmental impact of the product, but rather is limited on a defined set of indicators. Neither does it stimulate producers to continue to develop innovations to decrease environmental pressure once the ecolabel has been obtained. Indeed, by providing consumers with imperfect information, ecolabels can stimulate greenwashing [29]. Therefore, the inclusion of an IMTA label was not considered a fitting method to confer information to the public. Rather, a rating ecolabel was used.

Table 1. Overview of CE attributes and attribute levels.

Attribute	Attribute Level					Description
Production Location	National waters					The product is farmed in national waters
	Outside of national waters					The product is farmed outside national waters
Sustainability	Sustainability Level A					A 30% increase in environmental sustainability due to a move towards an IMTA production system
	Sustainability Level B					A 20% increase in environmental sustainability due to a move towards an IMTA production system
	Sustainability Level C					A 10% increase in environmental sustainability due to a move towards an IMTA production system
	Sustainability Level D					Monoculture production
Price per kg	Ireland	Israel	Italy	Norway	UK	
	€11	€9.08	€8.68	€7.80	€11.16	Low price in national market
	€17.50	€11.59	€11.42	€9.76	€18.14	Average price in national market
	€24.50	€12.82	€14.32	€11.70	€25.11	High price in national market
	€0	€0	€0	€0	€0	Status quo alternative price

A rated ecolabel approach was also used by Martinez-Espiñeira et al. [23] who estimated WTP for sustainability in food production processes and suggested by Aarset et al. [32] as a more viable approach to create bottom-up market incentives to shift to more sustainable production methods. In line with Martinez-Espiñeira et al. [23], the label design rates the environmental impact of the more sustainable production systems relative to conventional monoculture farms. The label design was based on the EU energy rating label [44]. This label is common on the European market for electronic appliances to indicate the amount of energy necessary to run an appliance in comparison to the product group. Several EU countries are using such environmental rating labels to inform consumer choices. The label used in the CE presents four levels of sustainability, ranging from A–D. The D label reflects the status-quo, or the environmental pressure resulting from monoculture production techniques. Respondents were informed that "integrated aquaculture attempts to mimic the natural ecosystem and produces less pollution. Depending on how the farms are set up, the amount of pollution will be different. The sustainability labels show you how good or bad the farming method is for the environment. The labels range from A–D, with A being best and D being worst for the environment. The labels show how much the environmental pressure of producing the salmon in the package has decreased from what we currently consider normal aquaculture (monoculture). Every level has a step of a 10% improvement in environmental sustainability." The labels A therefore being equivalent to a 30% decrease in environmental pressure. This information was shown on the labels to the respondents prior to the choice experiment.

Lastly, a monetary attribute was included in the CE to reflect a market situation and to enable the statistical derivation of the public's WTP for the other attribute levels. The CE price levels are based on the price range found in a survey of supermarket prices in each country. Based on these price ranges, a low, medium and high price were selected for each sample country. Within the model, the medium price level was taken as a base case. After the selection of the attributes and attribute levels, sixteen profiles were blocked into 4 versions of eight choice cards. Each choice card contained two alternatives and one opt-out option. The number of choice cards per respondent was limited to eight to avoid respondent fatigue. Variation in the attribute levels was achieved by using an efficient Bayesian experimental design based on the minimisation of the Db error criterion [45]. D-efficiency is a common approach for measuring experimental design efficiency [46]. A pilot study (n = 201) indicated that the attribute levels were appropriate as respondents selected the full price range when taking the choice experiment and indicated that they found the price range realistic when interviewed.

2.3. Modelling Approach

Discrete choice modelling is rooted in the concept of utility maximization. Lancaster [47] states that individuals derive utility, not from the consumption of a good, but from the set of attributes embodied by the good. The value of a good is therefore comprised of the bundle of attributes that the good holds. In a choice experiment, the value of specific attributes is elicited through statistical analysis. The Random Utility Model (RUM), developed by Mc Fadden [48] forms the basis for the statistical derivation of respondents' utility from the choice experiment data. The RUM states that the utility an individual derives from the consumption of a good consists of an observable and unobservable component. This can be expressed as

$$U_{in} = U(Z_{in,}S_n) + \varepsilon(Z_{in},\ S_n), \tag{1}$$

where U_{in} reflects the utility of alternative i as perceived by individual n in choice set C. Alternative i will be chosen over alternative j if $U_i > U_j$. This utility is comprised of two parts. First, the observable component (U) consist of the CE attributes (Z_{in}) and socioeconomic characteristics of the respondents (S_n), which can be captured by the model. Second, the unobservable component (ε_n) reflects unmeasured variations that fall outside the influence of the experiment. Utility cannot be estimated precisely due to the existence of the latent unobservable component, but utility measures can be maximised by minimising the error terms. The design of the CE aims to capture as much of the public's utility derived from the product as possible in the CE attributes, thus minimising the unobservable component. In the modelling process, the error term can be minimized by including information about the respondent and choice context indicators in the model, thereby including the influence of these terms on the choices made into the model.

Multiple econometric techniques to elicit utility from CE data have been developed. The basic discrete choice model is the conditional logit (CL). However, the CL is limited in that it carries the independence from irrelevant alternatives (IIA) assumption and it does not control for unobserved preference heterogeneity, i.e., variations of preferences across the sample. Therefore, other models have been developed, of which the most prominent ones are the random parameter logit (RPL) and the latent class (LC) model. Both models account for preference heterogeneity, albeit in different ways and relax the IIA assumption. The RPL generalizes the CL by allowing the coefficients of observed variables to vary randomly over people rather than being fixed [49]. In contrast, the LC model assesses the source of preference heterogeneity by identifying underlying latent groups from the data set. Both the RPL and LC models have been created for this study, but this paper presents the results of the LC analysis, as this model gave a better fit with regards to statistical information criteria, as will be elaborated on in the next section.

The LC model specifies that the mixing of preference intensities takes place over a finite group of c preference classes [40]. Members of each class have similar preferences that are not directly observable from the CE data, i.e., they are latent. The parameters of u, expressed as β, can be estimated by the LC model while assessing preference heterogeneity sources across classes of respondents. The LC model assumes that preferences vary across the classes based on a non-parametric distribution. Following Greene & Henscher [50], suppose β takes C possible values labelled $\beta 1, \ldots ; \beta c$ with probability $prob_c$ reflecting the LC model estimates. The choice probability can be expressed as:

$$Prob_{ni} = \sum_{c=1}^{C} prob_c \frac{\exp(\beta_C' x_{ni})}{\sum_j \exp(\beta_C' x_{nj})}, \tag{2}$$

where the expected probability of alternative *i* being chosen by any respondent is dependent upon the expected value of the class probability. Class probability, expressed as $prob_c$ is estimated in each LC model, along with the parameters of *u* (expressed as β).

The number of classes in the model is assessed using information criteria (IC) statistics for each of the models. There is no common accepted IC to determine the correct number of classes [51] so several IC are used in combination. In this case we examined the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC) and Hannan Quinn Information Criterion (HQ) statistics. These IC penalise for additional parameters to be included to determine the classes. The LC model has been used repeatedly in environmental economics [52,53] and, more specifically, for consumer preferences in seafood [54,55] and sustainability of seafood production [19,29].

The LC model was run for the pooled data set, containing the CE data of all the countries, and for each individual country. The model output is reported for the pooled and individual country level models. The model was additionally run on a subset of the CE data, excluding instances where sea bream was the product specified (Italy and Israel), as one could argue that the consumers' perceptions of production and preferences can vary across seafood species. As the results were similar in trends, coefficient strengths and marginal WTP estimates for CE attributes, the results of the full pooled data set including all country data are reported in this paper. (Results of the model, excluding the seabream CE data, are available from the authors upon request).

It should also be noted that there exists a high degree of heterogeneity in international responses towards seafood ecolabels. Several studies reviewed by Brécard et al. [29] point out numerous factors that determine the public's WTP. A number of these factors are the influence of culture, socioeconomic status, social norms, customs, political and moral values, institutions, political interests and political awareness [56–58]. Country specific dummies have been included in the model specification of the pooled data set to account for the effect of variations of these elements across the states. The comparison of several countries through a CE allows the researcher to assess if sustainability in the aquaculture production process is more valued in certain countries than others.

3. Results

Summary statistics for the entire sample of respondents (2520) are shown in Table 2. Overall, the sample was comparable to the national proportions in terms of gender, marital status, age and income. Even though 14% of the sample indicated they had heard of IMTA previously, a follow-up question asking for a description of IMTA resulted in no adequate description of IMTA being provided, suggesting that the true proportion of consumers familiar with IMTA is lower. This shows that consumers are not familiar with IMTA, regardless of whether or not IMTA experiments are taking place in the sample country. The majority of respondents indicated use of ecolabels either sometimes, most of the time, or always (1.86 average out of Likert 1–5).

Table 2. Summary statistics of choice experiment respondents.

n = 2520	Mean	Standard Deviation	Min.	Max
Demographic Variables				
Male (proportion)	0.46	0.50	0	1
Married/partner (proportion)	0.61	0.49	0	1
Third-level education (proportion)	0.44	0.50	0	1
Age (years)	41.1	12.72	18	65
Self-stated 'income below average' (proportion)	0.50	0.50	0	1
Attitudinal variables				
Have you ever heard of the term IMTA? (proportion)	0.14	0.35	0	1
Respondent uses ecolabels (Likert scale 1–4) [1]	1.86	0.92	1	4

[1] When you are buying seafood, do you look at ecolabels to decide which product you want to buy? Likert score (1–4): 1. Always, 2. Most of the time, 3. Sometimes, 4. Never.

The choice experiment data was analysed using NLOGIT6 statistical software. The search for the most appropriate specification (in terms of number of classes in model) consisted of modelling data assuming different numbers of latent classes for the individual country data sets and the pooled data set. The aim of this search was to develop a model that minimises the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC) and Hannan Quinn Information Criterion (HQ) statistics. These statistics are measures of how well the model expresses variation in observed data. In the interpretation of the model results, differences in preferences as expressed by differences in the attribute level parameter across the classes. Statistics of model performance are listed in Table 3. The pooled model and the models for Ireland and Israel failed to converge when specified with 4 classes. Interestingly, all statistics indicated the same class selection for each country, leading to the selection of a latent class (LC) model with three classes for the pooled data, three classes for Ireland and Israel and four classes for Italy, Norway and the UK. It has been shown that the different criteria can indicate different optimum class numbers and the researcher needs to then make a judgement call based on other factors such as variable significance across classes [40].

Table 3. Criteria for number of classes.

	Classes	Log.Lik.	AIC	BIC	HQ
Pooled	2	−15,821	31,703	31,948	31,783
	3	**−14,937**	**29,968**	**30,340**	**30,089**
	4	-	-	-	-
Ireland	2	−3058	6162	6307	6213
	3	**−2882**	**5834**	**6054**	**5912**
	4	-	-	-	-
Israel	2	−2876	5799	5943	5850
	3	**−2727**	**5524**	**5744**	**5602**
	4	-	-	-	-
Italy	2	−3265	6575	6720	6626
	3	−3151	6371	6592	6450
	4	**−2911**	**5916**	**6212**	**6021**
Norway	2	−2933	5911	6056	5963
	3	−2840	5750	5970	5828
	4	**−2598**	**5290**	**5586**	**5395**
UK	2	−3077	6200	6345	6251
	3	−2894	5858	6079	5936
	4	**−2782**	**5658**	**5955**	**5764**

Notes: Numbers in bold are maximised criterion for model selection.

3.1. Cross Country Models

Tables 4–8 present the individual country latent class models while the pooled cross country model is presented in Table 9. A set of consumer profiles based on the results of the latent class models are also presented in Table 10. Weighted marginal WTP estimates for the CE model attributes of production location and sustainability levels are presented separately in Table 11 and as a product containing a set of attributes in Table 12. Finally, an overview of the marginal WTP estimates per class in each of the country specific models and the combined pooled model is given in Appendix B.

Table 4. Model Ireland.

Ireland (*n* = 500)	**Latent Class** 3 Classes		
Choice	**Class 1**	**Class 2**	**Class 3**
Location	1.597 *** (0.195)	−0.461 (0.347)	1.414 *** (0.101)
Sustainability C	0.774 *** (0.225)	0.935 *** (0.353)	0.191 (0.119)
Sustainability B	0.95 *** (0.24)	−0.361 (0.532)	0.894 *** (0.135)
Sustainability A	1.87 *** (0.254)	1.242 *** (0.42)	1.772 *** (0.135)
Price	−0.467 *** (0.042)	−0.365 *** (0.053)	−0.095 *** (0.01)
Opt-out Alternative Specific Constant (ASC)	−11.956 *** (2.11)	−3.887 *** (1.084)	−2.512 *** (0.363)
Interaction terms with ASC			
Male	−0.092 (0.767)	1.489 *** (0.425)	−0.009 (0.15)
Third level Education	−0.168 (0.838)	0.869 *** (0.336)	0.253 * (0.149)
Age	0.002 (0.048)	0.01 (0.017)	0.038 *** (0.006)
Married	0.391 (0.971)	−0.455 (0.333)	−0.27 * (0.156)
Income	0.037 (1.021)	0.056 (0.309)	−0.093 (0.148)
Class Probability	0.393 *** (0.035)	0.123 *** (0.032)	0.484 *** (0.03)

*: $P < 0.1$; **: $P < 0.05$; ***: $P < 0.01$.

The latent class model output for the Irish data contained three latent classes, where the highest probability assigned was for class 3 (48%), followed by class 1 (39%) and class 2 (12%). The model showed significant positive consumer preference for seafood produced in Irish waters for the first (1.6, $P < 0.01$) and third (1.4, $P < 0.01$) classes. The second class showed a negative preference for the Irish produced attribute, but this coefficient was insignificant. With regard to sustainability in seafood production, Irish respondents showed a positive preference towards products with sustainability label C in class 1 (0.7, $P < 0.01$) and class 2 (0.9, $P < 0.01$), towards label B in class 1 (0.9, $P < 0.01$) and class 2 (0.9, $P < 0.01$) and towards label A in class 1 (1.9, $P < 0.01$), class 2 (1.2, $P < 0.01$) and class 3 (1.8, $P < 0.01$).

Overall, all latent classes were characterised by a positive preference for more sustainably produced seafood, although this preference was more clearly defined in class 1. Irish respondents had a significant negative preference in all classes for the price attribute (class 1: −0.05, $P < 0.01$; class 2: −0.4, $P < 0.01$; class 3: −0.1, $P < 0.01$) and the opt-out option (class 1: −11.9, $P < 0.01$; class 2: −3.9, $P < 0.01$; class 3: −2.5, $P < 0.01$). The models also include socio-demographic interaction terms where being male, married, having third-level education and income were interacted with the opt-out alternative specific constant (ASC). The interaction terms yielded insignificant parameters in the majority of classes in the Irish model. In class 2, demographic groups that opted out significantly more were male (1.5, $P < 0.01$) and highly educated (0.8, $P < 0.01$) respondents. In class 3 the elderly opted out significantly more than the other groups (0.04, $P < 0.01$).

Table 5. Model Israel.

Israel (***n*** **= 500)**	**Latent Class 3 Classes**		
Choice	**Class 1**	**Class 2**	**Class 3**
Location	1.87 *** (0.238)	1.114 *** (0.089)	0.625 *** (0.233)
Sustainability C	0.947 *** (0.257)	0.494 *** (0.112)	0.993 ** (0.39)
Sustainability B	1.742 *** (0.333)	1.332 *** (0.134)	1.252 *** (0.415)
Sustainability A	2.77 *** (0.362)	2.076 *** (0.132)	2.824 *** (0.39)
Price	−5.879 (0.279)	−0.366 *** (0.035)	−0.407 *** (0.073)
Opt-out Alternative Specific Constant (ASC)	−5.879 (737)	−5.645 *** (0.621)	−1.622 * (0.927)
Interaction terms with ASC			
Male	5.931 (128.6)	0.308 (0.271)	−0.668 ** (0.282)
Third level Education	18.478 (622.73)	−0.201 (0.259)	−0.256 (0.291)
Age	−3.983 (351.6)	0.023 ** (0.01)	0.03 *** (0.011)
Married	24.793 (120.8)	−0.097 (0.305)	−0.683 ** (0.331)
Income	21.07 (531.63)	0.186 (0.282)	0.27 (0.362)
Class Probability	0.323 *** (0.023)	0.527 *** (0.048)	0.15 *** (0.019)

*: $P < 0.1$; **: $P < 0.05$; ***: $P < 0.01$.

The preferred model for the Israel data contained three classes, where the highest-class probability was for class 2 (53%) and smaller probabilities for class 1 (32%) and class 3 (15%). Respondents from Israel showed a positive preference for nationally produced aquaculture produce in all classes (class 1: 1.89 $P < 0.01$; class 2: 1.1, $P < 0.01$; class 3: 0.6, $P < 0.01$). Across all classes, positive preferences for more sustainable aquaculture production were expressed that increased as sustainability levels increased, from label C (class 1: 0.9, $P < 0.01$; class 2: 0.5, $P < 0.01$; class 3: 1, $P < 0.01$) to B (class 1: 1.7, $P < 0.01$; class 2: 1.3, $P < 0.01$; class 3: 1.3, $P < 0.01$) to A (class 1: 2.8, $P < 0.01$; class 2: 2.1, $P < 0.01$; class 3: 2.8, $P < 0.01$). Israeli respondents expressed negative preferences for the price attribute (class 2: −0.04, $P < 0.01$; class 3: −0.04, $P < 0.01$), although this was insignificant for class 1 (−5.9, $P > 0.1$). With regard to the opt-out option, respondents showed a negative preference towards the opt-out option in class 2 (−5.6, $P < 0.01$) and class 3 (−1.6, $P < 0.05$), but this remained insignificant in class 1 (−5.9, $P < 0.1$). The interaction terms were insignificant in class 1. In class 2, the elderly opted out more (0.02, $P < 0.5$) and in class 3, respondents that opted out were more likely to be female (−0.7, $P < 0.05$) and unmarried (−0.7, $P < 0.05$).

Table 6. Model Italy.

Italy (*n* = 508)	**Latent Class** 4 Classes			
Choice	**Class 1**	**Class 2**	**Class 3**	**Class 4**
Location	2.59 *** (0.324)	3.774 *** (0.212)	0.77 *** (0.101)	1.129 *** (0.208)
Sustainability C	0.749 ** (0.321)	0.769 ** (0.342)	1.186 *** (0.166)	0.481 (0.432)
Sustainability B	1.479 *** (0.386)	0.46 (0.292)	2.537 *** (0.166)	0.847 ** (0.352)
Sustainability A	2.37 *** (0.357)	0.867 *** (0.193)	3.83 *** (0.139)	2.298 *** (0.298)
Price	−1.063 *** (0.105)	−0.093 ** (0.045)	−0.252 *** (0.022)	−0.371 *** (0.053)
Opt-out Alternative Specific Constant (ASC)	−2.958 (0.00001)	−0.097 (0.663)	−4.326 *** (0.418)	−2.518 *** (0.647)
Interaction terms with ASC				
Male	−0.144 (0.00001)	−0.698 *** (0.26)	0.354 ** (0.167)	0.615 *** (0.154)
Third-level Education	0.058 (0.00001)	−1.316 *** (0.309)	0.27 * (0.159)	−0.124 (0.157)
Age	−1.939 (0.00002)	0.013 (0.012)	0.057 *** (0.008)	0.029 *** (0.009)
Married	0.126 (0.00001)	0.477 ** (0.236)	−0.02 (0.179)	0.384 ** (0.188)
Income	−0.55 (0.0001)	−0.328 (0.315)	−1.39 *** (0.214)	−0.538 *** (0.196)
Class Probability	0.18 *** (0.02)	0.224 *** (0.016)	0.448 *** (0.035)	0.144 *** (0.017)

*: $P < 0.1$; **: $P < 0.05$; ***: $P < 0.01$.

The Italian sample was divided into four latent classes, with the probability of class 3 being the largest (45%), followed by class 2 (22%), class 1 (18%) and class 4 (14%). Overall, preferences for the attributes followed similar patterns, although differences exist between the classes in terms of attribute coefficient significance. Italian respondents have a positive preference for aquaculture produced in national waters across all classes (class 1: 2.6, $P < 0.01$; class 2: 3.8, $P < 0.01$; class 3: 0.8, $P < 0.01$; class 4: 1.1, $P < 0.01$). Respondents predominantly show a preference for aquaculture products with higher sustainability labels, although some differences exist. In class 1 and 3, preference is significant and positively related to sustainability across label C (class 1: 0.7, $P < 0.05$; class 3: 1.2, $P < 0.01$), label B (class 1: 1.5, $P < 0.01$; class 3: 2.5, $P < 0.01$) and label A (class 1: 2.4, $P < 0.01$; class 3: 3.8, $P < 0.01$). Although the model produced statistically insignificant results on label C (class 4) and label B (class 2), respondents expressed a positive and significant preference for aquaculture products with the highest sustainability label (A) across all classes. Respondents had a negative preference for products with a higher price across all classes. Preferences were negative for the opt-out option in the choice cards, although these were insignificant in class 1 (−3, $P > 0.1$) and class 2 (−0.1, $P > 0.1$). The interaction terms between demographic groups and the opt-out option were insignificant in most cases. None of the interaction terms were significant in class 1, while in other classes respondents were more likely to opt out when they were male (class 2: −0.7, $P < 0.01$; class 3: 0.4, $P < 0.05$; class 4: 0.6, $P < 0.01$), educated below third-level education (class 2: −1.3, $P < 0.01$), married (class 2: 0.5, $P < 0.05$; class 4:

0.4, $P < 0.05$), over 45 years of age (class 3: 0.06, $P < 0.01$; class 4: 0.03, $P < 0.01$) or had an income below the national average (class 3: −1.4, $P < 0.01$; class: 4 0.5, $P < 0.01$).

Table 7. Model Norway.

Norway (*n* = 501)	**Latent Class 4 Classes**			
Choice	**Class 1**	**Class 2**	**Class 3**	**Class 4**
Location	1.214 *** (0.105)	0.044 (0.349)	1.19 *** (0.25)	3.461 *** (0.259)
Sustainability C	0.398 *** (0.135)	0.77 * (0.434)	1.103 ** (0.446)	0.242 (0.244)
Sustainability B	1.191 *** (0.157)	0.002 (0.547)	3.035 *** (0.465)	0.062 (0.204)
Sustainability A	2.001 *** 0.16437	−0.138 (0.51)	4.442 *** (0.478)	0.463 ** (0.213)
Price	−0.886 *** 0.056	−1.22 *** (0.21)	−0.235 *** (0.083)	−0.187 *** (0.063)
Opt-out Alternative Specific Constant (ASC)	−10.832 *** 1.059	−0.796 (1.612)	−5.397 *** (1.146)	−1.367 * (0.712)
Interaction terms with ASC				
Male	1.329 ** (0.566)	−0.872 * (0.479)	0.223 (0.391)	−0.323 (0.253)
Third level Education	0.141 (0.464)	−2.494 *** (0.49)	0.005 (0.459)	−0.399 (0.292)
Age	−0.021 (0.018)	−0.14 *** (0.023)	0.222 *** (0.02)	0.002 (0.009)
Married	0.326 (0.480)	1.46 *** (0.454)	−2.154 *** (0.474)	0.05 (0.261)
Income	−0.916 (0.585)	−1.411 ** (0.703)	−0.763 * (0.411)	0.305 (0.276)
Class Probability	0.475 *** (0.014)	0.091 *** (0.024)	0.167 *** (0.026)	0.267 *** (0.025)

*: $P < 0.1$; **: $P < 0.05$; ***: $P < 0.01$.

The preferred model for the Norwegian data divided the respondents up into four latent classes, where class membership was the highest for class 1 (48%), followed by class 4 (27%), class 3 (17%) and class 2 (9%). Considerable preference differences were modelled across the Norwegian classes. National production location was preferred by class 1 (1.2, $P < 0.01$), class 3 (1.2, $P < 0.01$) and class 4 (3.5, $P < 0.01$), but remained insignificant for class 2. Sustainable aquaculture produce was preferred across all sustainability labels in class 1 (label C: 0.4, $P < 0.01$; label B: 1.2, $P < 0.01$; label A: 2, $P < 0.01$) and class 3 (label C: 1.1, $P < 0.05$; label B: 3, $P < 0.01$; label A: 4.4, $P < 0.01$). Preferences for the sustainability of aquaculture production were however insignificant for class 2 and class 4. All latent classes in the Norwegian data had a statistically significant preference for products with lower prices and a negative preference for the opt-out option, with the smallest class (2) being statistically insignificant for the alternative specific constant. With regard to the interactions between demographic variables and the alternative specific constant, Norwegian respondents were more likely to opt-out when male in class 1 (1.3, $P < 0.05$), when not having completed third-level education in class 2 (−2.5, $P < 0.01$), when under the age of 45 in class 2 (−0.1, $P < 0.01$) and over 45 in class 3 (0.2, $P < 0.01$), when married in class 2 (1.5, $P < 0.01$) and unmarried in class 3 (−2.2, $P < 0.01$) and when the respondent's income is below the national average in class 2 (−1.4, $P < 0.05$).

Table 8. Model United Kingdom.

UK (*n* = 510)	**Latent Class 4 Classes**			
Choice	**Class 1**	**Class 2**	**Class 3**	**Class 4**
Location	1.40 *** (0.195)	1.479 *** (0.387)	0.02 (0.233)	0.609 *** (0.092)
Sustainability C	0.935 *** (0.248)	1.219 * (0.67)	1.103 *** (0.274)	0.224 (0.137)
Sustainability B	1.638 *** (0.326)	2.17 *** (0.798)	1.438 *** (0.375)	0.905 *** (0.162)
Sustainability A	2.664 *** (0.378)	3.126 *** (0.805)	2.227 *** (0.349)	1.485 *** (0.162)
Price	−1.129 *** (0.112)	−0.37 *** (0.132)	−0.972 *** (0.105)	−0.107 *** (0.027)
Opt-out Alternative Specific Constant (ASC)	−12.034 *** (2.96)	−3.074 *** (0.974)	−0.968 (0.98)	−6.837 *** (1.233)
Interaction terms with ASC				
Male	−0.645 (0.794)	1.129 ** (0.532)	0.607 ** (0.304)	0.851 ** (0.346)
Third level Education	−0.756 (0.604)	−1.183 *** (0.427)	−0.208 (0.393)	0.695 ** (0.305)
Age	0.023 (0.028)	0.057 *** (0.019)	−0.067 *** (0.024)	0.058 *** (0.018)
Married	−0.783 (0.783)	2.746 *** (0.552)	−2.202 *** (0.354)	1.304 *** (0.383)
Income	−0.328 (0.981)	1.534 *** (0.398)	−0.507 (0.318)	1.143 *** (0.386)
Class Probability	0.389 *** (0.03)	0.098 *** (0.028)	0.172 *** (0.04)	0.342 *** (0.033)

*: $P < 0.1$; **: $P < 0.05$; ***: $P < 0.01$.

Data from the British respondents were modelled assuming four classes, consisting of two classes with a class probability of 39% (class 1) and 34% (class 4) and two classes with lower class probabilities of 17% and 10%. British respondents showed a positive preference for aquaculture products produced in national waters (class 1: 1.4, $P < 0.01$; class 2: 1.5, $P < 0.01$; class 4: 0.6, $P < 0.01$), although this preference was statistically insignificant for class 3 (0.02, $P > 0.1$). Respondents also expressed a positive preference for products from more sustainable aquaculture production processes, across all labels; although label C was insignificant in class 2 ($P > 0.5$) and class 4 ($P >.01$). This suggests that these classes prefer only larger increases in sustainability. All classes showed a statistically significant negative preference for the price attribute ($P < 0.01$) and all but class 3 ($P > 0.1$) had a negative preference for selecting the opt-out option in the choice cards ($P < 0.01$). In terms of interaction terms, in no demographic group opted out significantly more on average in class 1. In class 2 however, respondents selected the "I would not purchase either" option significantly more when they were male (1.1, $P < 0.05$), when their highest completed education level was below third level (−1.2, $P < 0.01$) or if they were married (2.7, $P < 0.01$). In class 3, the opt-out was selected more by respondents that were male (0.6, $P < 0.05$), under 45 years of age (−0.1, $P < 0.01$) or unmarried (−2.2, $P < 0.01$). In class 4, respondents opted out more when male (0.9, $P < 0.05$), completed third level education or higher (0.7, $P < 0.05$), are over 45 years of age (0.1, $P < 0.01$) and have an income higher than the national average (1.1, $P < 0.01$).

Table 9. Model pooled data.

Pooled (*n* = 2520)	**Latent Class 3 Classes**		
Choice	**Class 1**	**Class 2**	**Class 3**
Location	1.126 *** (0.046)	0.225 *** (0.067)	3.142 *** (0.155)
Sustainability C	0.482 *** (0.054)	0.482 *** (0.054)	0.127 (0.119)
Sustainability B	1.039 *** (0.066)	2.016 *** (0.126)	0.230 * (0.122)
Sustainability A	1.734 *** (0.066)	3.211 *** (0.139)	0.495 *** 0.125
Price	−0.585 *** (0.022)	−0.197 *** (0.011)	−0.120 *** (0.014)
Opt-out Alternative Specific Constant (ASC)	−10.571 *** (0.514)	−1.657 *** (0.26)	3.210 *** (0.379)
Interaction terms with ASC			
Male	−0.304 * (0.184)	0.094 (0.088)	0.495 *** 0.125
Third level Education	0.178 (0.183)	−0.230 *** (0.087)	0.186 (0.174)
Age	0.0343 *** (0.007)	0.029 *** (0.004)	−0.006 (0.006)
Married	0.031 (0.187)	−0.156 * (0.090)	−0.265 * (0.148)
Income below average	0.276 (0.187)	−0.239 *** (0.091)	0.156 (0.144)
Ireland	−6.053 *** (0.513)	−0.289 * (0.170)	0.495 *** 0.125
Italy	−0.019 (0.401)	0.709 *** (0.160)	−3.311 *** (0.247)
Norway	1.940 *** (0.285)	3.705 *** (0.230)	−3.330 *** (0.252)
UK	2.635 *** (0.294)	0.761 *** (0.171)	0.493 ** (0.244)
Class probability	0.543 *** (0.018)	0.278 *** (0.009)	0.178 *** (0.010)

*: $P < 0.1$; **: $P < 0.05$; ***: $P < 0.01$.

In the 3-class model for the pooled data set, 54% (*n* = 1,161) of the respondents we assigned to the first class, 28% (*n* = 705) to the second class and 18% (*n* = 454) to the third class. The coefficients of all parameters are significant on the 1% level, with the exception of the third class, where the lower sustainability level (c) was insignificant. The interaction terms with the opt-out ASC varied strongly between the classes.

3.2. Consumer Profiling across Classes

In Table 10, consumer profiles based on the latent class parameters are described. Here it should be noted that the classes are not mutually exclusive but latent, meaning that respondents are assigned a probability of membership in each case. Respondents are thus not assigned 100% to any single class.

Consumer profiling is based on the coefficient values in each class. A total of five consumer profiles were created. The profiles identified in the latent classes are (1) the "Green Buyer", (2) the "Local Buyer", (3) the "Determined Buyer", (4) the "Flexible Buyer" and (5) the "Economic Buyer".

Table 10. Classification of preferred models of pooled and country data.

		Green Buyer		Local Buyer		Determined Buyer		Flexible Buyer		Economic Buyer		Indifferent Buyer	
	n	Class	%	Class	%	Class	%	Class	%	Class	%	Class	%
Pooled	**2520**	Class 2	28	Class 3	18	Class 1	54	-	0	-	0	-	0
Total			**28**		**18**		**54**		**0**		**0**		**0**
Ireland	**500**	Class 3	48	-	0	Class 1	39	-	0	-	0	Class 2	12
Israel	**500**	Class 3	15	Class 2	53	-	0	Class 1	32	-	0	-	0
Italy	**508**	Class 3	45	Class 2	22	-	0	Class 1	18	Class 4	14	-	0
Norway	**501**	Class 3	17	Class 4	27	Class 1	48	-	0	Class 2	9	-	0
UK	**511**	Class 3	17	Class 4	34	Class 1	39	-	0	-	0	Class 2	10
Total			***28***		***27***		***25***		***10***		***5***		***4***

3.2.1. The Green Buyer

The first two profiles relate to the main CE attributes; production location and sustainability level. Respondents in the "Green Buyer" class are characterised by a strong preference for sustainable seafood production. The class represents a positive coefficient for the sustainability attributes, which translates into a WTP for the sustainability attributes that is significantly higher than in the other classes and compared to other attributes.

The second class from the pooled data model is labelled as the green buyer due to its positive preference for the sustainability attributes C, B and A (attribute coefficients (and standard error) of 0.48 (0.05), 2.02 (0.13) and 3.21 (0.14) respectively) and the comparatively low preference for production location. Elder people were more likely to select the opt–out (0.03 (0.004)), while highly educated respondents (−0.23 (0.09)), low income respondents (−0.24 (0.09)) and married respondents (−0.16 (0.09)) were less likely to select the opt-out. With regard to the country interactions, respondents from this class are more likely to select the opt-out when they are Italian (0.71 (0.16)), Norwegian (3.71 (0.23)) or British (0.76 (0.17)), compared to the base case.

Latent classes characterised by their high utility associated with sustainability are modelled for every country and represented a large proportion of the population of Ireland (class 3, probability 48%) and Italy (class 3, probability 45%) and smaller proportions for Norway (class 3, probability 17%), the UK (class 3, probability 17%) and Israel (class 3, probability 15%). The profile of the Green Consumer is represented by the largest proportion of respondents (class 2, probability 28%) and the only latent class to be modelled in every data set. The allocation towards green or local buyer profiles is based on the comparative coefficients of the sustainability attribute and on the height of the WTP for the individual attributes in the specific class. Although characterised by their preference for sustainability, the Irish, Israeli and Norwegian respondents in this profile also have a positive utility for national production location paired with their preference for higher sustainability.

3.2.2. The Local Buyer

The "Local Buyer" has a strong positive preference for seafood that is produced in national water, as opposed to imported seafood. This preference is elicited from a positive coefficient for the location attribute and a WTP for the location attribute that is high, both in comparison to the other attributes as well as for the location attribute WTP in other classes.

Members of the third class from the pooled model had strong positive preferences for fish produced in national waters (3.14 (0.16)). The sustainability attribute coefficients did not show a clear preference pattern, although the highest sustainability attribute is significant (0.5 (0.13)). With regard to representativeness of the sample, male respondents in this class were more likely to select one of the purchasing decisions than women (0.5 (0.13)). Compared to the base case, male respondents from Ireland (−0.5, (0.13)), Italy (−3.31 (0.25)) and Norway (−3.33 (0.25)) are less likely to select the opt-out, while respondents from the UK select the opt-out significantly more (0.49 (0.24)). However, the preference for the opt-out is still negative for all countries, i.e., respondents from all countries prefer to select a purchasing option over the "I would not buy any of these products, even if this product was on my shopping list" option.

In the single country analysis, the profile of the local buyer can be attributed to 27% of the respondents, spread over Israel (class 2, probability 53%), the United Kingdom (class 4, probability 34%), Norway (class 4, probability 27%) and Italy (class 2, probability 22%). Although Irish respondents have among the highest WTP for nationally produced seafood in the sample, no latent class was allocated to the local buyer profile in the Irish model.

3.2.3. The Determined Buyer

The determined and flexible buyer profiles relate to the shopping habits of respondents and their resoluteness in making purchasing decisions. Respondents in the "Determined Buyer" profile are characterised by their determination to buy what is on their shopping list, regardless of the attributes of the product. This is reflected by a negative coefficient for the alternative specific constant in the model.

The first class from the pooled data model is labelled as 'determined buyer' due to its strong negative preference for the opt-out option (−10.57 (0.51)). The class is further characterised by positive coefficients for the national production location (1.13 (0.05)) and the sustainability attributes C, B and A (0.48 (0.05), 1.04 (0.07) and 1.73 (0.07) respectively). The country interactions terms in the pooled model indicate that Irish respondents have a stronger tendency to select one of the purchasing options (−6.05 (0.51)) compared to the base case of Israelis, whereas Norwegian and the British respondents selected the opt-out option more (in 2 out of the 3 classes in the Norwegian case and for all classes in the UK case) in comparison to the base case (1.94 (0.29) and 2.64 (0.29), respectively). This means that the results of the model cannot be generalised over the Norwegian and British public as much as over the other sample countries, as they have selected the opt-out more. However, considering the strong negative coefficient for the constant, Norwegian and British respondents have a negative preference for the opt-out; i.e., they prefer to select a purchasing option over the opt-out option, but this preference is significantly weaker than in the other sample countries. This tendency is consistent for these countries across the different classes.

Across the individual country models, the profile of the determined buyer was allocated to latent classes in Ireland (class 1, probability 39%), Norway (class 1, probability 48%) and the United Kingdom (class 1, probability 39%), together accounting for 25% of the sample population. The modelled classes produced significant coefficients for all attributes, but were identified as determined buyer classes due to the strength of the negative coefficient for the opt-out ASC; it was over 6 times the nearest coefficient in the class in Ireland, over 5 times in the Norwegian class and 4.5 in the UK class. The modelling of these classes is based on the purchasing habits rather than preference for one of the attributes, but the respondents represented by these classes did display significant preferences for the CE attributes.

3.2.4. The Flexible Buyer

In contrast to the determined buyer, the "Flexible Buyer" shifts easily from one product to the other when the product attributes do not fit the respondents' preferences. This is expressed by the absence of a significant negative coefficient for the alternative specific constant. The determined and flexible buyers can however still have strong preferences for the CE attributes, which should be recognised in the interpretation of the latent class models.

In the individual country models, a latent class flexible buyer are assumed for Israel (class 1, probability 32%) and Italy (class 1, probability 18%), together representing 10% of the total sample population. Classes were allocated to the flexible buyer profile based on their respondents' tendency to switch to other (substitute) products and their lack of a preference for lower prices. They were allocated to the flexible profile due to insignificant coefficients for the constant, which reflects a lack of a detectable preference for buying the type of product the respondent intended to buy when entering the shop. In the Israel class, no significant preference for lower priced products was visible. As the classification of these latent classes is based on shopping habits, it should be recognised that the classes in Israel and Italy both have significant positive coefficients for the CE attributes production location and sustainability, thus contributing to the WTP of those attributes.

3.2.5. The Economic Buyer

The "Economic Buyer" profile captures respondents' price sensitivity. Respondents in this class have a preference for products with lower prices. Although not observed in the pooled data set, the economic buyer profile is allocated to classes in Italy (class 4, probability 14%) and Norway (class 2, probability 9%), together representing 5% of the total sample population. The economic buyer profile was allocated according to the negative preference for the price variable. The Italian class holds positive preferences for the sustainability and location attributes, but these preferences are only significant for the higher sustainability attribute levels. This suggests that these individuals pay extra only for larger increases in sustainability. In the Norwegian class 2, price was the only variable that was significant (at the 5% level). In terms of representativeness of the latent classes for the sample population, this profile is comparatively weakly represented.

Table 11. Weighted marginal WTP for CE attributes across countries by the preferred models.

	Model (Number of Classes)	Nationally Produced	Sustainability A	Sustainability B	Sustainability C
Pooled	LC (3)	€6.02 ***	€6.89 ***	€4.16 ***	€2.45 ***
UK	LC (4)	€6.23 ***	€15.18 ***	€9.44 ***	€3.43 ***
Italy	LC (4)	€11.33 ***	€10.21 ***	€6.21 ***	€4.28 ***
Ireland	LC (3)	€8.35 ***	€10.97 ***	€5.21 ***	€1.93 ***
Israel	LC (3)	€3.41 ***	€10.29 ***	€5.23 **	€3.27 ***
Norway	LC (4)	€6.45 ***	€4.88 ***	€2.88 ***	€1.40 *

*: $P < 0.1$; **: $P < 0.05$; ***: $P < 0.01$.

Table 12. Price premium for seafood with varying attributes of pooled data.

Combination Attribute Levels		Weighted WTP for Attribute Combination			
Production Location	**Sustainability Label**	**Class 1**	**Class 2**	**Class 3**	**Weighted**
National	A	€4.89	€17.49	€30.21	€12.91
National	B	€3.70	€11.40	€26.10	€9.84
National	C	€2.75	€7.68	€26.10	€8.29
International	A	€2.97	€16.34	€4.11	€6.89
International	B	€1.78	€10.26	€1.91	€4.16
International	C	€0.82	€6.53	€1.06	€2.45

Table 11 lists the marginal willingness-to-pay for the change in attribute levels. Estimates reported are weighted for the latent class membership probabilities. The public's marginal WTP for seafood produced in national waters varies from €3.41 (in Israel) to €11.33 (in Italy) and is estimated at €6.02 for the pooled data set, ceteris paribus. The marginal WTP for the sustainability attributes vary from €1.40 (Norway) to €4.28 (Italy) for sustainability label C, from €2.88 (Norway) to €9.44 (UK) for sustainability label B and from €4.88 (Norway) to €15.18 (UK) for sustainability label A. The pooled data analysis produced estimates of €2.45, €4.16 and 6.89 per kilo of unfrozen product that has sustainability label C, B and A, respectively, ceteris paribus. The pattern in WTP estimate is comparable between countries. Marginal WTP for both sustainability and national production location is positive and increases as sustainability increases. This pattern holds over all countries. However, difference does exist in the magnitude of marginal WTP estimates. The average marginal WTP for CE attributes is the highest in the UK, followed by Italy, Ireland, Israel and lastly Norway.

4. Discussion

This paper presented the results of a latent class analysis of CE data with the aim of assessing the market potential of sustainable seafood production techniques, such as IMTA. Latent classes were modelled for data sampled in Ireland, Israel, Italy, Norway and the United Kingdom both separately and for the pooled data from all countries. Classes were allocated to consumer profiles according to the estimated attribute preference parameters signs and significance, leading to respondents in each class being labelled as green, local, determined, flexible, or economic buyers. More specifically, latent classes in the pooled data model were identified as green (28%), local (18%) and determined (54%) buyers. While these profiles remain dominant in the country data analysis, a number of smaller profiles were detected that remained unidentified under the three class model on the pooled data set.

The profiles of the green and local consumer reflect respondents' preferences for the CE attributes sustainability and production location, whereas the determined and flexible profiles reflect how easily an individual shifts to an alternative product based on the product attributes. Interestingly, the proportion of the public assigned to the profile of green consumer (28%) is comparable to the proportion of consumers labelled green consumers by the OECD [59] (27%). As the determined buyer class covers a relatively large proportion of the respondents in Ireland (39%), Norway (48%) and the UK (39%) the general public of the sampled countries seems to be characterised as determined buyers rather than as a flexible buyer.

The public's WTP is positive for all CE attributes and across the sample countries and the pooled data, indicating that the public is willing to pay a price premium for products produced in a more sustainable method such as IMTA. Marginal WTP for the locally produced attribute is estimated in the pooled data at €6.02, ceteris paribus, indicating a willingness to pay a price premium for seafood products that are produced in national waters. The results also indicate that the public is willing to pay a price premium for products that are produced more sustainably. This WTP increases as the degree of sustainability increases by decreasing the environmental impact by 10% (€2.45—sustainability label C), 20% (€4.16—sustainability label B) or 30% (€6.89—sustainability label A) per kilo of product.

Price premiums are mentioned as a method of stimulating seafood producers to shift to more sustainable production techniques such as IMTA [60]. However, this is conditional upon the additional profits going to producers, rather than to retailers. Considering the international character of the seafood market and the power of retailers in the market, some form of governance may be necessary if bottom-up pressure by the public is to steer the industry to become more sustainable. The EU may well be the best suited institution to govern seafood market steering policies in Europe, as it holds some transnational power and can create a standardised instrument that transcends national market boundaries and works at the European level [61] in contrast with the fragmented approach of national governments.

Given the strong competition in the globalised seafood market, the European aquaculture industry can match the global industry only when it creates a valuable market position for itself. For example, the Irish salmon industry recovered from a decline in production after a combination of disease and negative market conditions by carving out a high-value niche market for organic salmon [62]. The European aquaculture industry could come closer to matching global growth rates by creating a similar niche for its products. Production methods such as IMTA could expedite the development of such a sustainable niche market.

The significant WTP for more sustainable forms of aquaculture does not in itself guarantee higher profits for producers that switch to such production methods. This will also depend on the marginal costs of providing higher sustainable levels in production. Given the potential synergies across the products produced in an IMTA system with possible reduction in costs associated with feed loss and waste processing (plus increasing demand for sustainable produced food), the marginal cost could actually decrease in the long run but this remains an area for future research. Further research is also needed in terms of the pooled model specification. The model presented controls for non-observed heterogeneity in mean preferences. In this type of cross-country study however, consumers may interpret and process choice tasks and situations differently [63]. Control for this scale heterogeneity could improve the fit of the pooled model.

The creation of an ecolabel as demonstrated in this survey could simultaneously fulfil multiple functions; for the public, they provide previously hidden information on the environmental impact of a product, allowing them to maximize their utility; for a producer, they provide the opportunity to differentiate their product and increase their market value; while governments use ecolabels as a policy instrument to stimulate environmentally friendlier production to reach policy goals. An increasing proportion of the European public is aware of the environmental impact of seafood production and is willing to pay a price premium for more sustainable products. Public awareness and willingness-to-pay analysis can therefore be considered a tool to stimulate the European aquaculture industry while facilitating blue growth and reaching the goal of 'Good Environmental Status'. Simultaneously, an EU ecolabel guarantees the public that the product observes EU production standards, which, as Magennis et al. [64] points out could reassure those individuals reluctant to purchase seafood that is imported from countries where regulations are perceived as insufficient.

Furthermore, an ecolabel as proposed in this paper provides information to the public on the degree of environmental impact. A common criticism towards ecolabels is that they do not provide information on the degree of environmental improvement, and green grading schemes have been proposed by scholars [32]. A sustainability grading label provides this information to the public and continually stimulates producers to decrease the environmental impact of their production process, so as to reach a higher ecolabel tier. Lastly, a lack of knowledge and trust in regulatory organisations, paired with distrust towards the food industry, and ignorance and scepticism about the independence of certifiers, has been identified as elements that are decreasing the ecolabel impact [32]. A grading label as proposed has the advantage of consumer familiarity and trust, as this is a widely used and accepted label across EU countries.

Seafood preferences for sustainability and production location can be generalized over countries in terms of preference patterns, but WTP estimates were heterogeneous in degree. Differences among countries can have implications for the success of eco-labelling programs. Differences in socioeconomic status, knowledge on environmental issues, price sensitivity or the perceived importance of other seafood attributes that the ecolabel competes with may all impact on the success of a new ecolabel [24]. These differences highlight the need for flexible implementation of cross border eco-labelling programs, as well as the need for education of the European public on environmental issues and their role as responsible consumers. Finally, a key aspect of investment in IMTA will be the extent to which consumers are willing to pay higher prices for fish and shellfish which are produced using this technique. The results presented here highlight the fact that consumers are willing to pay a price premium for the additional sustainability IMTA systems could provide, although the location of such systems will also remain an important consideration in any purchasing decision.

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Appendix A

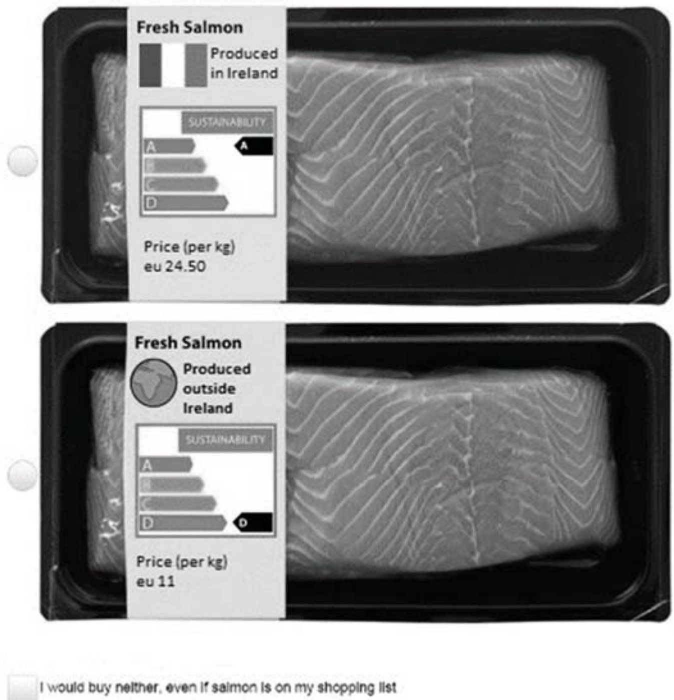

Figure A1. Example Choice Card as Presented in the Choice Experiment.

Appendix B

Table A1. Marginal WTP per Latent Class per Country and for the Pooled Model.

	Class 1	Class 2	Class 3	Class 4	Weighted
Ireland					
Class probability	39% ***	12% ***	48% ***		100%
Location	€1.35 ***	€−0.16	€7.16 ***		€8.35 ***
C	€0.65 ***	€0.32 **	€0.97		€1.93 ***
B	€0.80 ***	€−0.12	€4.53 ***		€5.21 ***
A	€1.58 ***	€0.42 **	€8.98 ***		€10.97 ***
Israel					
Class probability	32% ***	53% ***	15% ***		100%
Location	€0.28 ***	€1.60 ***	€1.52 *		€3.41 ***
C	€0.14 ***	€0.71 ***	€2.42 **		€3.27 ***
B	€0.26 ***	€1.92 ***	€3.05		€5.23 **
A	€0.41 ***	€2.99 ***	€6.89 *		€10.29 ***
Italy					
Class probability	18% ***	22% ***	45% ***	14% ***	100%
Location	€0.45 ***	€9.07 **	€1.37 ***	€0.44 ***	€11.33 ***
C	€0.13 **	€1.85 *	€2.11 ***	€0.19	€4.28 ***
B	€0.26 ***	€1.11	€4.52 ***	€0.33 **	€6.21 ***
A	€0.41 ***	€2.08 **	€6.83 ***	€0.89 ***	€10.21 ***

Table A1. *Cont.*

	Class 1	Class 2	Class 3	Class 4	Weighted
Norway					
Class probability	48% ***	9% ***	17% ***	27% ***	100%
Location	€0.65 ***	€0.003	€0.85 ***	€4.95 ***	€6.45 ***
C	€0.21 ***	€0.06	€0.78 *	€0.35	€1.40 **
B	€0.64 ***	€0.0002	€2.16 ***	€0.09	€2.88 ***
A	€1.07 ***	€−0.01	€3.15 ***	€0.66 **	€4.88 ***
United Kingdom					
Class probability	39% ***	10% ***	17% ***	34% ***	100%
Location	€0.48 ***	€0.39 **	€0.003	€1.95 ***	€2.83 ***
C	€0.32 ***	€0.32	€0.20 ***	€0.72	€1.56 ***
B	€0.56 ***	€0.57	€0.25 ***	€2.90 ***	€4.29 ***
A	€0.92 ***	€0.83 *	€0.39 ***	€4.76 ***	€6.90 ***
Pooled					
Class probability	54% ***	28% ***	18% ***		100%
Location	€1.93 ***	€1.15 ***	€26.10 ***		€6.02 ***
C	€0.82 ***	€6.53 ***	€1.06		€2.45 ***
B	€1.78 ***	€10.26 ***	€1.91 *		€4.16 ***
A	€2.97 ***	€16.34 ***	€4.11 ***		€6.89 ***

*: $P < 0.1$; **: $P < 0.05$; ***: $P < 0.01$.

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sustainability

Article

Sustainability Descriptive Labels on Farmed Salmon: Do Young Educated Consumers Like It More?

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Abstract: Despite the efforts to make fish sustainable, it is largely unknown if young educated consumers' taste of fish and their willingness to pay more for fish is influenced by positively framed messages regarding sustainable farming practices. This research investigated if a positively framed description of sustainable farming opposed to positively framed descriptions of flavour, health benefits, or socially responsible farming, influences young consumers' liking, and willingness to pay for farmed salmon. Young consumers of fish ($n = 119$) randomly tasted Fresh and hot Smoked salmon and rated their liking and willingness to pay more on structured line scales. The salmon were labelled with either a description of sustainable farming practices, flavour benefits, nutrition/health benefits, socially responsible farming practices, or no descriptions. Descriptive labelling about Sustainability ($p = 0.04$), Flavour ($p = 0.01$), and Health/nutrition ($p = 0.01$) significantly increased consumers' liking of Fresh salmon compared to Fresh salmon without labelling. No such a difference was found between the social responsibility label and the sample without labels ($p = 0.2$). Participants were willing to pay more for 250 g of Fresh and Smoked Salmon with descriptive labels (Fresh: \$9.3 ± \$0.003; Smoked: \$10.1 ± \$0.003), than for the same Salmon without such labels (Fresh: \$9.0 ± \$0.06; Smoked: \$9.8 ± \$0.08) ($p < 0.001$). The sustainability descriptive label had no added benefit above other descriptive labels. The liking and buying intent were, for all labels and fish types, strongly correlated ($r = 0.80$, $p < 0.001$). In conclusion, sustainability labelling is promising, but does not differentiate from other positively framed messages.

Keywords: sustainability; sensory; seafood; consumers

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1. Introduction

Global fish consumption has rapidly increased in the past decades. The health benefits associated with fish consumption are well recognized and health organisations across the world recommend that consumers eat around 2 to 3 servings of fish per week [1,2]. Especial young consumers consume suboptimal levels of fish [3,4]. Large quantities of fish consumption, although beneficial to health, are thought to put an unsustainable strain on the current fish supply [5]. The FAO has estimated that about 31.4% of the commercialised fish stocks are overfished and biologically unsustainable. The focus on sustainable practices, including farming fish in a sustainable manner [6,7], is therefore important from an industry as well as a consumer point of view.

There is an increased focus on sustainable seafood practices, which is reflected by an increase in sustainability certifications shown on the front of the pack, which aims to inform consumers about the positive sustainability or eco-friendly profile of the product. It is estimated that there are close to 50 different labels worldwide related to sustainability and eco-friendliness of seafood, some of those are supported by official certifications as assessed by independent organisations (see Reference [8] for review). Although some studies have suggested that information about sustainability has a positive influence on product choice [9,10] and willingness to pay [11,12], other studies failed to see such an effect [13]. More importantly, to our knowledge, none of the studies which investigated the impact of sustainability information on seafood perception actually included consumers tasting the product and assessed their liking of the taste of seafood with sustainability information.

Considering that food liking is one of the most important determinants of food choice, including fish [14,15], the importance to positively influence consumers' food liking and buying intentions of sustainable fish is instrumental to increase the economic viability of the aquaculture sector. Taste is determined by the food, but also by information, which is provided to consumers at the point of purchase and at the point of consumption. Previous research with a variety of commodities suggests that the liking of products can be influenced by descriptive labelling [16]. Descriptive labelling provides consumers with additional information about the product (e.g., country of origin, production methods, ingredients, health and taste benefits) and is mostly placed on the front of the food package (also referred to as "front of the pack"), to attract consumers' attention. Descriptive labelling in this context can either be a single word or phrase (e.g., made in Australia, made by high-pressure technology), or a more elaborated marketing description such as "Belgium black forest double chocolate cake [17]". A variety of studies have suggested that descriptive labels influence consumers' taste perception and buying intention. For example, descriptive labelling on wine bottles focused on the region of origin (e.g., Dakota vs. California) can increase consumers' liking of wine [18]. Descriptions about the production process of milk (e.g., long vs. short shelf life milk) can alter consumers' liking of milk, depending on consumers' beliefs about the different milk production processes [19]. Ingredient information associated with health and/or taste benefits placed on the front of packages, such as "contains soy" [20], "reduced in salt" [21,22], "low fat" [23], and labelling emphasising the exclusivity of a product (e.g., "Belgium black forest double chocolate cake" [17] or "X-ray vision carrots" [24] can alter consumers' liking of unhealthy, as well as healthy, products. In addition, logos and messages related to social responsibility, commonly seen on food products such as coffee, chocolate [25,26], rice [27], as well as seafood, seem to increase consumers' willingness to buy the product [28].

Along the same line, labelling focused on sustainability can influence consumers' liking of food as shown with various commodities such as chocolate, coffee, and lamb (see Reference [16] for review). However, consumers need to understand the sustainability label [29] and feel a high involvement with sustainability [30]. For some consumers, sustainable practices concerning fish are of high importance and relevance [10,15,16]. However, not all consumers place a high importance on sustainability. For them, labelling focused on sustainability is less likely to influence food liking, partly because they do not see an immediate personal benefit of sustainable foods [31]. Egocentric consumers who do not feel highly connected with "sustainability" might view products labelled as "sustainable" as not benefitting them in the near future. Whereas for those who are less egocentric and those who feel a strong involvement with the welfare of others and the greater good, descriptions focused on sustainability are more likely to influence their liking of foods. It is therefore likely that descriptive labelling concerning sustainability is specifically powerful for consumers who are highly concerned and involved in sustainability [10].

Research in Western countries such as the UK, USA, and Spain, suggest that young highly educated adults show a positive attitude towards sustainability [32] and are concerned about sustainability [33,34]. Research specifically focused on fish with a sustainable label suggests that those who buy fish with a sustainability label are mainly either young singles or families with older aged children living at home [35]. Several studies suggest that the sustainability of fish is valued by consumers as evidenced by the increased preference for seafood products with a sustainability label [9], but the influence of sustainability-related information on young educated consumers' liking of the taste of seafood is underexplored

The present study investigated if a positively framed description of sustainable farming as opposed to positively framed descriptions of flavour, health benefits, or socially responsible farming, influences young highly educated consumers' liking and willingness to pay for farmed salmon. Specifically, two differently prepared Atlantic salmon (*Salmo salar*) products, fresh raw salmon and hot smoked salmon, were tested, and the messages/labels tested in this study were focused on the production methods of the feed (aquafeed) used in salmon farms. The focus on aquafeed, rather than on other production variables, was selected to represent one of the highest recurrent costs of aquaculture practices and has attracted some criticisms with respect to its sustainability. For example, at the moment, the amount of fish from the ocean needed to feed farmed salmon can be seen as not sustainable. However, aquafeed has the capability of directly affecting all the parameters studied (including nutrition/health and flavour). In addition, feed companies are typically the largest players in the aquaculture production chain, and accordingly have a greater capability of intervention, R&D investment, and marketing. A positive consumer perception of aquafeed will help the industry to further develop and sell sustainable fish products.

2. Materials and Methods

Regular consumers of salmon tasted and rated their liking and willingness to pay for two different types of salmon products; fresh raw salmon and hot smoked salmon. The four randomly assigned descriptive marketing type labels were focused either on sustainability, flavour, nutrition/health, or social responsibility (Table 1). Each combination of the type of salmon and labelling was presented once to each consumer. In addition, they tasted the two types of salmon without descriptive labelling. All participants tasted the fresh raw, as well as smoked, salmon in all label combinations, which resulted in 10 samples for each participant. After tasting all samples, participants rated the perceived importance of sustainability, flavour, nutrition/health, or social responsibility on food in general. In addition, they were asked how much they considered sustainability, flavour, nutrition/health and social responsibility when actually buying food in general or fish specifically.

Table 1. The four marketing descriptive labels used for the consumer taste test.

Label Type	Description
Social responsibility	This unique salmon has been farmed with a novel feed developed to maximise the social responsibility, and the overall ethical quality, of the entire production cycle; ingredients used were preferentially locally produced and all produced and purchased under fair trade conditions, greatly supporting local and regional communities by providing premium prices to farmers, that guarantee safe working conditions and fair remuneration for their employees.
Flavour	This unique salmon has been farmed with a novel feed developed specifically towards improving the flavour and taste of its fillet; the feed has been carefully formulated via also the expert support of high quality selected chefs, to highlight fresh sea aroma of salmon fillet, improving its firmness, juiciness, brightness and brilliant colour, and making this salmon perfectly delicious, rich, flavourful and succulent.
Sustainability	This unique salmon has been farmed with a novel feed developed specifically towards improving its overall sustainability; only certified and sustainably sourced agricultural products and no wild caught marine products, have been used to formulate this feed; with focus on the feed overall digestibility and nutrient bioavailability and resulting in no nitrogen nor phosphorus wastes being released into the ocean and rivers.
Nutrition/Health	This unique salmon has been farmed with a novel feed developed specifically towards improving the nutritional qualities of its fillet; a lean product, rich in protein of high biological value, packed with antioxidants, essential trace elements and the entire suite of vitamins, and an abundance of beneficial long chain omega-3 fatty acids, making this salmon the most nutritious and healthy of all superfoods.

The testing was conducted in computerised, partitioned sensory booths in the Centre for Advanced Sensory Science at Deakin University, and data was collected using Compusense Cloud as part of the Compusense Academic Consortium (Compusense Inc., Ontario, Canada. The study design and protocol was approved by the Deakin University Human Ethics Committee (HREC 2012-162); all consumers provided informed, written consent prior to study commencement. The consumers were asked to refrain from eating, drinking (except room temperature water), brushing teeth or chewing gum for one hour prior to testing.

Stimuli: The fresh Atlantic salmon was collected from a wholesaler the morning prior to the sensory tests (Clamms Seafood, Yarraville, Victoria, Australia). All fresh salmon originated from the same batch, same farm, and was harvested and processed the evening before. The hot smoked salmon was sourced by the same wholesaler and came from the same farm as the fresh salmon. The smoked salmon originating all from the same batch and were collected frozen on the morning prior to the sensory tests. Salmon products were offered to the consumers to taste in portions of 5 g at room temperature in clear medicine cups. In total, the participants tasted five fresh and five smoked pieces of salmon.

Participants: All consumers were students enrolled in an undergraduate degree at Deakin University and consumed fish at least once every month. Eight participants were excluded because they did not want to taste the salmon. A total of 119 participants (108 female, 11 male, 23 $\pm$ 3.9 yrs) were included in the final analyses of the study.

Procedure: At the start of the test, consumers were told that they were going to taste sashimi (fresh raw salmon, hereafter referred to as Fresh) and hot smoked salmon (hereafter referred to as Smoked). They were also told the following: "Just to inform you, we have given you some more information about the fish you will be tasting". Consumers tasted four samples of Fresh and Smoked salmon to which a descriptive label was attached and a sample without labelling in a randomised order (see Table 1). In order to make sure the participants read the description without making them aware of the real purpose of the study, they were told: "in the interest of time could you please read the description while you are tasting, this will make the tasting and rating a bit quicker". After the five salmon samples were tasted, consumers waited one minute before another control and four samples with randomly assigned descriptive labels were presented. The design was balanced and randomised in such a way that all participants tasted all combinations of fish type and descriptive labels. The offering of Fresh and Smoked salmon was alternated. Consumers rinsed their mouth with water after tasting each piece of salmon.

Measurement of liking and willingness to pay: While tasting each sample consumers were asked to score on a 10 cm structured line scale how much they liked the salmon (hereafter referred to as "liking"). The lines were anchored with "not liked at all" (-5 cm) on the left side to "like very much" on the right side (5 cm), and neutral in the middle (0 cm). The line was separated by three evenly spread markers. After consumers rated liking they were asked how much they wanted to pay for the salmon they just tasted by showing the following text on screen: "regular salmon sells for about $10 per 250 g. How much would you be willing to pay for 250 g of the salmon you just tasted?" Underneath this question, they were presented with a 10 cm structured line scale with the following evenly spread markers $8, $9, $10, $11, $12. Participants could mark the line anywhere between $8 and $12. The reference price was deliberately provided to make sure that all participants had the same reference price point in mind when answering the question.

Measurement attitudes and behaviour: After all fish samples were tasted, participants were asked the following questions. "You are about to buy fish. What does make you decide to buy a particular fish?" Participants were presented with 4 statements (e.g., the fish is tasty; the way the fish is farmed is good for the environment; the way the fish is farmed is good for the community and farms; Consuming the fish will be good for your health) and were asked to rank these statements from most to least decisive. In addition, they were asked the following questions: "How important is it to you that the fish you buy (a) gives fair wages to farmers? (b) is produced with sustainable methods? (c) is tasty? (d) is good for your health? Participants were asked to score these statements on a 5 points scale (e.g., 1 = not important at all; 2 = not important; 3 = between not important and important; 4 = important; and 5 = very important. This score is referred to as the "importancy score"). Next, they were asked to rate how often they considered Sustainability, Flavour, Health/nutrition, or Social responsibility at the point of purchase when buying fish (1 = never, 2 = sometimes, 3 = often, 4 = always). Next, consumers were asked how often (i.e., less than once a month, 1–3 times per month, once per week, twice per week, 3–4 times per week, 5–6 times per week, every day) they consumed raw, steamed/grilled/baked, fried and/or canned fish. Basic demographic data (i.e., age, gender) were collected at the end of the questionnaire.

Two separate linear univariate models were used to investigate the role of the salmon type and label type on (1) liking and (2) willingness to pay. More specifically, a general linear univariate model with "descriptive labelling" and "Salmon type" as fixed factors and "liking" as the dependent variable was applied to investigate the influence of "descriptive labelling" and "salmon type" on "liking". A second linear model with "descriptive labelling" and "Salmon type" as fixed factors and the "price willing to pay for salmon" as the dependent variable was applied to investigate the influence of "descriptive labelling" and "salmon type" on "willingness to pay". Post-hoc analyses with Bonferroni correction were carried out to identify if the "sustainability label" influenced liking and willingness to pay in a different way as the remaining labels did. In order to take into account that the data was not independent (e.g., all participants rated all samples on liking and willingness to pay), participants' ID was included as a random factor but not as variable. p-values < 0.05 were considered statistically significant.

To investigate the importance of sustainability, flavour, health/nutrition, and social responsibility, the importancy score of sustainability was compared against the importancy score of flavour, health/nutrition, and social responsibility by using a Wilcoxon non-parametric test for two related samples. In which, not important at all = 1, not important = 2, between not important and important = 3, important = 4, very important = 5). A similar analysis was conducted to investigate if sustainability was more often considered when buying fish than flavour, health/nutrition, or social responsibility.

Sustainability-focused consumers were identified as those who reported often or always to consider "sustainability" when buying food. Taste focused consumers were identified as those who reported always to consider "taste" when buying food. Health-focused consumers were identified as those who reported always to consider "health" when buying food. When consumers reported to always consider taste and health when buying food, they were counted as both taste focused and health-focused consumers. It is important to point out that taste and health focus was used as a way to look at the sample set, rather than a comparison of taste versus health-focused consumers. All statistical procedures were performed with IBM SPSS statistics Version 22, 64-bit edition.

3. Results

3.1. Subject Characteristics

The majority of consumers were female (91%) and had at least completed year 12 of secondary school (Table 2). As shown in Table 3, fish was most frequently consumed (more than once a month) as steamed/grilled/ baked and/or canned fish. Raw and fried were the least popular preparation methods. Virtually all consumers reported that flavour and/or health were important to very important when it came to food choices. Sustainability and social responsibility were the least important aspects of food (p < 0.0001). This is also a reflection of how often participants considered sustainability when buying fish. That is, 4.2% of participants "always" considered sustainability when buying fish. This was significantly lower than the frequency at which they considered flavour, health/nutrition, or social responsibility when buying fish (p < 0.0001) (see Tables 3–5).

Table 2. The demographic characteristics (mean ± sem) of participants in the consumer taste test.

	Overall	**Health Focused (n = 59)** [1]	**Taste Focused (n = 68)**
Age (yrs)	23 ± 3.9	23 ± 3.4	23 ± 3.4
Male	9% (11)	5.1% (3)	6% (4)
Female	91% (108)	95% (56)	94% (64)

[1] Taste focused consumers were identified as those who reported to always consider "taste" when buying food. Health-focused consumers were identified as those who reported to always consider "health" when buying food. When consumers reported to always consider taste and health when buying food, they were counted as both taste focused and health-focused consumers. Taste and health focus was used as a way to look at the sample set, rather than a comparison of taste versus health-focused consumers.

Table 3. The participants' frequency of fish and fish product consumption.

	<1/Month	1–3/Month	1/Week	2/Week	3–4/Week	5–6/Week	Every Day
Raw (including sushi)	47.9%	29.4%	10.9%	5.9%	5%	1%	1%
Steamed, grilled or baked	14.3%	37.8%	26.9%	13.4%	6.7%	1%	-
Fried (including take away)	63.9%	27.7%	6.7%	1.7%	-	-	-
Canned (salmon, tuna, sardines, etc.)	34.5%	23.5%	21.0%	13.4%	7.6%	-	-

Table 4. The percentage of participants who judged sustainability, flavour, health/nutrition, or social responsibility as not important at all to very important.

	Sustainability [1]	Flavour	Health/Nutrition	Social Responsibility
Not important at all	-	-	-	0.8%
Not important	5.0%	-	-	5.0%
Between not important and important	34.5%	5.0%	3.4%	32.8%
important	47.9%	41.2%	46.2%	51.3%
Very important	12.6%	53.8%	50.4%	10.1%

[1] Sustainability was significantly less important than flavour and health/nutrition $p < 0.0001$.

Table 5. The percentage of participants who considered sustainability, flavour, health/nutrition, or social responsibility when buying fish (point of purchase).

	Sustainability [1]	Flavour	Health/Nutrition	Social Responsibility
Never	26.9%	4.2%	1.7%	24.4%
Sometimes	45.4%	5.0%	9.2%	36.1%
Often	23.5%	23.5%	42.9%	29.4%
Always	4.2%	67.2%	46.2%	10.1%

[1] Sustainability was significantly less considered when buying fish than flavour, health/nutrition, and social responsibility $p < 0.0001$.

3.2. Influence of Descriptive Labelling on Liking and Willingness to Pay

The general linear univariate model showed a main effect of type of salmon offered on liking ($p < 0.05$) and a borderline significant main effect of descriptive labels on liking ($p = 0.07$). Fresh salmon was liked less than Smoked salmon (Fresh: −1.7 cm ± 0.13 cm vs. Smoked: 1.4 cm ± 0.14 cm) ($p < 0.001$). When investigating the influence of labels on each salmon type individually, it was found that descriptive labelling about Sustainability (−1.1 cm ± 0.37 cm, $p = 0.04$), Flavour (−0.95 cm ± 0.37 cm, $p = 0.01$), and Health/nutrition (−1.3 cm ± 0.37 cm, $p = 0.01$) significantly increased consumers' liking for Fresh salmon compared to the same fish without labels (−1.8 cm ± 0.37 mm). No such difference was found between the Social responsibility label (−1.1 cm ± 0.35 cm) and the fish without labels ($p = 0.2$). Post hoc analyses revealed no significant difference between the Sustainability descriptive label and the remaining descriptive labels (Figure 1). Descriptive labelling did not influence consumers' liking for Smoked salmon (no labels: 1.3 cm ± 0.36 cm vs. Smoked labelled: 1.6 cm ± 0.07 mm) ($p = 0.60$) (Figure 1).

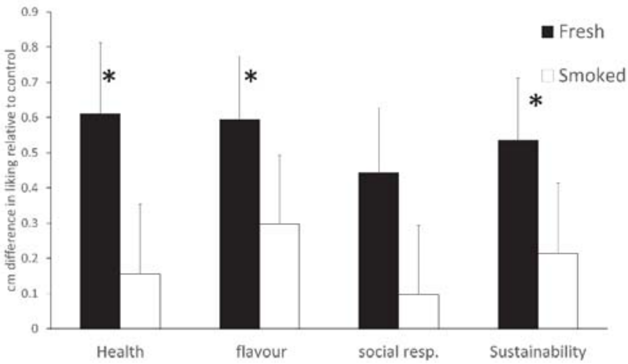

Figure 1. The relative difference (cm) (mean ± sem) in liking compared to fish without labels (control), shown for different descriptive labels (i.e., health, taste, social responsibility and sustainability). Positive (maximum = +10 or negative difference (maximum = −10) indicates that fish with a descriptive label is more or less liked respectively, than the control fish. * indicates a significant difference ($p < 0.05$) compared to the same salmon without a descriptive label.

The general linear univariate model showed a main effect of the type of salmon offered ($p < 0.001$) and a main effect of the descriptive labels ($p < 0.001$) on the willingness to pay. Participants were willing to pay more for Fresh and Smoked Salmon with descriptive labels (Fresh: \$9.3 ± \$0.003; Smoked: \$10.1 ± \$0.003), than for the same Salmons without such labels (Fresh: \$9.0 ± \$0.06; Smoked: \$9.8 ± \$0.08) ($p < 0.001$). No significant differences were observed between the different descriptive labels (Figure 2). Liking and buying intent were, for all labels and fish types, strongly correlated $r = 0.80$, $p < 0.001$.

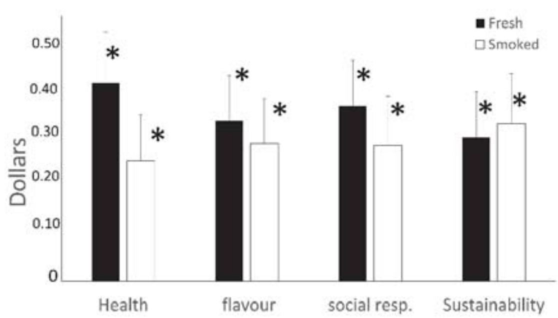

Figure 2. The difference in \$ amount (mean ± sem) that participants are willing to pay more for 250 g of salmon (e.g., fresh, smoked) with different labels (i.e., health, taste, social responsibility and sustainability) compared to control fish without labels (cm). * indicates a significant difference ($p < 0.05$) compared to the same salmon without a descriptive label.

3.3. Sustainability, Health, and Taste Focused Consumers

Seventy-one consumers (60%) were classified as sustainability-focused consumers. The influence of sustainability labelling on fish liking and buying intentions of sustainably focused consumers was not different from the influence of these labels on none-sustainable focused consumers.

When only selecting consumers who highly focused on taste, it was found that the flavour descriptive label increased liking of fresh salmon (control: −1.8 ± 0.4 vs. flavour label: −1.0 ± 0.4) ($p < 0.05$). The remaining descriptive labels did not influence liking. The health-focused consumers were, however, more willing to pay more for any of the fresh salmon with descriptive labels, than for the same salmon without such labels. Although health-focused consumers' liking of the hot smoked salmon was not influenced by any of the descriptive labels, they were willing to pay more for smoked salmon which carried either the sustainability or the social responsibility descriptive label compared to the same salmon without such labels ($p < 0.05$).

Descriptive labels did not influence taste focused consumers' liking of fresh nor smoked salmon. However, taste focused consumers were willing to pay more for the fresh salmon with a flavour description, than for the same fresh salmon without a descriptive label. Such difference was not found for the nutrition/health, social responsibility or sustainability label.

4. Discussion

The present study demonstrated that descriptive labels, including those focused on sustainability, can increase the liking and the amount that young highly educated consumers want to pay for salmon. However, descriptive labelling about sustainable fish feed as such did not increase the liking and "willingness to pay" more than labels focused on health and taste. This was even the case for those consumers who thought sustainability was very important. The influence of descriptive labelling depends on consumers' liking of the product and consumers' focus on taste and health. To our knowledge, this is the first study that investigated the influence of a variety of descriptive labelling (including sustainability) on the experienced liking of fish during consumption. The results can be explained and should be interpreted relative to, the positive halo effect descriptive labelling has on consumers.

The sustainability, flavour, and the nutrition/health descriptive label had the largest influence on participants' liking of fresh salmon, whereas the social responsibility description did not seem to influence liking. Yet, consumers were more likely to pay more for salmon when it carried a descriptive label about social responsibility. A recent study found that although consumers are willing to pay more for socially responsible labelled seafood, the influence is weaker compared to the influence of sustainability labelling of seafood on the willingness to pay [11]. Potentially, consumers did not see a logical link between social responsibility and the taste of fish. Therefore, the direct benefit (i.e., a tasty salmon) of socially responsible fish is less prominent compared to the direct benefit of fish, which is labelled as flavoursome and/or nutritious. Previous research suggests that the links between healthy and tasty, and flavour description and tasty are rather salient for consumers [36].

Although the sustainability label increased the liking of fresh salmon, a similar influence was not found for hot smoked salmon. Potentially sustainability labels have more influence on products which are moderately liked, rather than those which, without the presence of a descriptive label, are already highly liked. This can partly be explained by a ceiling effect; recall that all hot smoked salmon was very well liked. Furthermore, descriptive labelling did increase the price consumers were willing to pay for hot smoked salmon. This suggests that the descriptive labels had some positive effect on the evaluation of smoked salmon. Nevertheless, the strong positive correlation between taste liking and willingness to pay suggests that taste is likely to be a major contributor to the amount of money consumers want to pay for salmon. It needs, however, to be noted that in the present study, the willingness to pay was always measured after participants tasted the salmon. Therefore, the increase in willingness to pay can be a result of the labels participants saw, as well as the taste they experienced.

Grouping consumers based on their health and taste focus is relevant as shown by the present study. Taste focused consumers place more emphasis on taste than non-taste focused consumers, which can explain why only the flavour descriptive label was able to increase the price these taste focused consumers were willing to pay for salmon. With this in mind, it is particularly interesting that those who were focused on sustainability did not react differently to the sustainability description compared to those who were less focused on sustainability. This suggests that the increase in liking and willingness to pay is likely a result of a general effect of a positive descriptive label, rather than a specific effect of a sustainability description. In general, the participants in the present research showed far more interest in flavour and health of food than in sustainability. This is important information for the fish industry. Especially because the participants we tested are, in general, interested in sustainability, but relative to flavour and health it seems to be less important.

It has previously been found that product labelling can influence consumers' willingness to buy seafood [37]. What sets the present study apart from previous studies is that consumers actually tasted the fish rather than reporting what they thought the fish would taste like. The combination of market and sensory research (e.g., sensory marketing) is an approach which has gained attention and popularity in the past 15 years [38,39]. It is now well understood that external product cues can influence sensory perception and that the combination of sensory inputs needs to be in congruence with the marketing message. Like in the present study, these effects are usually small. However, due to the advances in food production and product development, differences between competitor products are often very small. Small but significant changes in liking, by using sensory marketing, can make a large difference in how a product performs on the market [38].

There are limitations which need to be taken into consideration when interpreting the results. This study was specifically focused on young highly educated, mainly female, adults. The reasoning behind this is that these consumers are more likely to be interested in sustainability [32–34,40]. If sustainability labelling has any effect on liking, it should at least have an influence on this select sample and it did to a certain extent. However, the sustainability label failed to be different compared to either a health or flavour focused label. In addition, at least for the participants in the present study, sustainability is not seen as important as health or flavour. This suggests that those working in the fish industry should at least temper their expectations of the potential attraction sustainability labelling has on young educated consumers. Having said that, the present study has been focused on a very select sample and follow up studies should be conducted with a sample of a more general population. Lastly, it is important to acknowledge that the present study only measured liking and not consumption per se. However, it has been repeatedly suggested that liking strongly correlates with consumption [41].

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sustainability

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The Sustainability Conundrum of Fishmeal Substitution by Plant Ingredients in Shrimp Feeds

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Abstract: Aquaculture is central in meeting expanding global demands for shrimp consumption. Consequently, increasing feed use is mainly responsible for the overall environmental impact of aquaculture production. Significant amounts of fishmeal are included in shrimp diets, causing dependency on finite marine resources. Driven by economic incentives, terrestrial plant ingredients are widely viewed as sustainable alternatives. Incremental fishmeal substitution by plant ingredients in shrimp feed was modeled and effects on marine and terrestrial resources such as fish, land, freshwater, nitrogen, and phosphorus were assessed. We find that complete substitution of 20–30% fishmeal totals could lead to increasing demand for freshwater (up to 63%), land (up to 81%), and phosphorus (up to 83%), while other substitution rates lead to proportionally lower impacts. These findings suggest additional pressures on essential agricultural resources with associated socio-economic and environmental effects as a trade-off to pressures on finite marine resources. Even though the production of shrimp feed (or aquafeed in general) utilizes only a small percentage of the global crop production, the findings indicate that the sustainability of substituting fishmeal by plant ingredients should not be taken for granted, especially since aquaculture has been one of the fastest growing food sectors. Therefore, the importance of utilizing by-products and novel ingredients such as microbial biomass, algae, and insect meals in mitigating the use of marine and terrestrial resources is discussed.

Keywords: aquaculture; shrimp feed; fishmeal; plant ingredients; marine resources; terrestrial resources

1. Introduction

Global fish consumption per capita almost doubled from 9.96 kg in 1961 until 19.86 kg in 2013, and capture fisheries and aquaculture are important contributors to the global food supply, producing in 2013 approximately 17.7% of the total 30 g capita^{-1} day^{-1} animal protein, which is more than poultry (17.4%), pig (15.7%), and bovine (12.0%) [1]. In 2015, global per capita fish supply reached 20.2 kg [2], and an annual increase in fish consumption of 0.3% until 2030 is projected [3] with a growing global middle-class increasing demand for high value species [2]. In 2015, 59.9% of the global fish stocks were fully fished, while 33.1% of the global fish stocks experienced fishing at an unsustainable level. Since 2000, capture fisheries have been close to their production limits of 90 million metric tons (MT) annually. As a result, the aquaculture sector is growing faster than any other food-producing sector, and in 2016, aquaculture contributed to 46.8% of the global fish production [2].

Currently, more than 50% of the global shrimp supply originates from aquaculture with an estimated production volume between four and five million MT in 2015 [4], making it one of the largest consumers of aquafeed [2,5] and most valuable aquaculture production group [2,3]. Additionally, the shrimp industry is one of the dominant consumers of fishmeal in the aquaculture sector [6,7]. To meet demand for a growing industry in the face of a finite supply of marine ingredients, feed manufacturers have decreased the inclusion of fishmeal in commercial diets [6,8,9]. Aquafeed is shifting towards crop-based ingredients, mainly driven by economic incentives [8–10], as the relative price of fishmeal increases compared to common plant ingredients, such as soy protein concentrate, cereal, and wheat gluten [2,7,11].

Fishmeal substitution by plant ingredients is considered to be environmentally sustainable, as it reduces dependency on finite marine resources [6,10]. However, the nutritional requirements of certain aquatic species may limit the amount of fishmeal substitution due to essential nutrients, which are variable or imbalanced in terrestrial plant ingredients [10,12]. Additionally, substituting fishmeal by plant ingredients would shift resource demand from the oceans onto the land, potentially adding pressure to the land-based food production systems [13–15], affecting the environment, biodiversity, and availability and prices of crops [8,16,17]. Minor price changes could have significant impacts in developing countries, as 50% of the household income is spent on food [18], and a price increase of one percent could result in an estimated 16 million undernourished people [19]. These potential implications do not contribute to a sustainable diet as defined by the Food and Agriculture Organization (FAO) [20], neither is it in line with the Sustainable Development Goals (SDGs) of the United Nations (UN) of food security, hunger reduction, and protection of life on land and in the sea.

Current knowledge suggests that aquaculture growth and its increasing demand for plant ingredients in aquafeed could affect agricultural supply [17] and its resources, such as land, freshwater, and fertilizer [8,16]. However, the quantitative impact is relatively unknown.

2. Aquafeed Interactions with Marine and Terrestrial Resources

Aquaculture and capture fisheries are interdependent [16,17], as fishmeal and fish oil are used in aquafeeds (mainly for finfish and crustacean diets) [5,7,9]. Fish oil and fishmeal originates from small pelagic fish and an increasing share of fish processing waste (on average a proportion of 25% to 35%) [2,3,8]. The fraction of capture fisheries for fishmeal production is relatively stable, and therefore an increasing inclusion of fishery by-products could contribute to global fishmeal supply but could affect its nutritional value [2]. Aquaculture saw an extremely fast increase in global fishmeal consumption share from 10% in 1980 to 73% in 2016 [7], while the aquafeed sector accounted for approximately 4% of global feed production [16]. While shrimp aquaculture consumed 16% (approximately 6.18 million MT) of the global aquafeed production (approximately 39.62 million MT) in 2012 [5], it consumed 31% (approximately 1 million MT) of the fishmeal in aquaculture (IFFO, personal communication, 2018). Global fishmeal production is around five million MT annually, and its future production may be affected by an increasing demand, climate change, and variability (e.g., El Niño) [9,12,21]. In response, shrimp feed manufacturers have decreased the inclusion of fishmeal from a global range of 19–40% in 2000 to 11–23% in 2014, while the global fish oil inclusion range stabilized (around 0–2%) (IFFO, personal communication, 2018). Future fishmeal inclusion in shrimp feed are expected to further decline and stabilize around 6% in 2025 [11]. Additionally, total shrimp production fed on aquafeeds is expected to increase from 84% in 2012 to 90% in 2025 (approximately 8.6 million MT) [5]. The growth in aquaculture production and increasing feed demand could have significant environmental impacts, as most life cycle assessments (LCAs) suggest that feed probably accounts for over 90% of the environmental impact [22]. However, this impact is variable depending on the type, source, and form of feed ingredients.

Aquatic animals generally convert feed more efficiently because of their buoyancy in water and efficient protein digestion and therefore use less feed compared to terrestrial animals [23,24]. Consequently, aquafeed ingredients originating from terrestrial animal by-products often embodies more resources than ingredients from fisheries or agriculture [8]. Furthermore, the inclusion of some ingredients such as those rendered animal by-products in aquafeeds is restricted in some parts of the world, but new regulations are now permitting some avian derived materials in the EU [7]. Other ingredients are limited by consumer perceptions, availability, and price [2,8]. Therefore, plant ingredients have become the principal alternatives to substitute fishmeal [6,10]. However, these alternatives come at a cost, as agricultural production for aquafeed ingredients (rapeseed/canola, soybean, corn, nuts, and wheat) required a land area as large as Iceland (~10 million ha) in 2008 [14]. At the same time, water demand for these aquafeed ingredients was estimated between 31–35 km^3, from which 3.53 km^3 was consumed for *Litopenaeus vannamei* production and 1.1 km^3 for *Penaeus monodon* production [15], the two main shrimp species in aquaculture today [4]. Some argue that there is not sufficient land available for agricultural expansion, as 4.9 billion ha (which is approximately 40% of the total land surface in 2005) [25] (FAO, 2014) currently occupies 91% of the approximately 5.41 billion ha suitable for agriculture [26]. It is estimated that one-fourth of the global terrestrial surface functions as grazing land for livestock, and that animal feed crop production occupies around one-third of the global crop land [27]. This land is also under pressure by climate change [2,14] and increasing demand for food, biofuels, and bio-based materials [18,28]. Additionally, water scarcity is also expected, as agriculture consumes 70% of freshwater resources [11], which could affect feed and fish production [8,16]. The increasing production of non-ruminants such as pigs and poultry requires arable land compared to the production of ruminants such as cattle and sheep that requires grazing land, resulting in an increase in freshwater and nutrient demand for feed [29]. Additionally, the increasing use of phosphorus, which is a limiting nutrient for food production, raises concerns [23,30,31], while the combination with nitrogen in fertilizers causes eutrophication and dead zones in coastal marine ecosystems [8,31,32]. This agrifood system may therefore be reaching a scenario analogous to "Tragedy of the Commons" [33], as independent users in the form of small and medium-sized enterprises (SMEs), multinationals, and industries in a globalized market overexploit and deplete finite resources driven by self-interest and a rapidly growing world population.

An excessive dependency on the utilization of plant ingredients for aquaculture could lead to deleterious effects on the environment and indirectly impact human health by altering the nutritional value of the aquaculture products [8,14,17], likely underestimating the impacts of this feed transition. There is a lack of knowledge exchange between all involved stakeholders, the aquaculture industry, policy makers, and people depending on aquaculture for income and/or food [34]. In this respect, our principal objectives were to quantify firstly the resource implications [freshwater, land, nitrogen, phosphorus, and (wild) fish] of soybean meal inclusion to reduce the dependency of marine sources, and secondly examine the inclusion of alternative plant ingredients typically included in modern shrimp feeds, such as rapeseed meal, pea meal protein, and corn gluten meal.

3. Materials and Methods

We modeled the natural resource demands of a transition to plant-based ingredients in shrimp feed formulations. In this study, feed formulation algorithms were used to create unique feed formulations per shrimp species, with intermediate declining steps of 20% fishmeal substitution by plant ingredients while accounting for the dietary requirements of individual shrimp species. These diets were modeled in combination with a comprehensive multifactorial assessment of marine and terrestrial resource demand for agricultural crop production and processed ingredients.

The methodology for the feed formulations and data input is explained in Section 3.1. This is followed up (Section 3.2) by a detailed explanation of the marine and terrestrial resource demand dataset for each ingredient, which was based on FAO data and scientific literature. The last (Section 3.3) explains the model simulations and runs and includes an overview of the modeled feed formulations, ingredients, and their respective resource demand values (Table 1). These data are modeled in order to calculate the range in resource demands of the combined ingredients in the feed formulation with the equation explained at the end of Section 3.3. The model forming the basis of our investigation is available as an excel file in the supplementary materials.

3.1. Feed Formulations and Scenarios

We estimated the impact of fishmeal substitution with plant ingredients by developing contemporary shrimp feed diets using the feed formulation software [35] FeedSoft™ (FeedSoft Corporation, Dallas, TX, USA). This software uses linear optimization to calculate the most cost-efficient feed formulation based on dietary requirement data and global market ingredient prices. Nutrient requirement data of shrimp were obtained from the National Research Council (NRC) 2011 database [36], and global ingredient prices were obtained from the International Hammersmith Commodity Index Database [37]. These prices fluctuate; therefore, we selected the commodity prices of September 2018 and converted them to Euros (€) for input into the FeedSoft™ feed formulation software.

We developed feed formulations for the two most dominant species in shrimp farming, namely *Litopenaeus vannamei* (whiteleg shrimp) with a share of 76.1% of the total shrimp production volume in 2017, and *Penaeus monodon* (black tiger shrimp), which covers the second biggest share estimated at 12.5% [4,38]. Traditional shrimp feed formulations include between 20% and 30% fishmeal [39], where 30% was commonly applied for *P. monodon* [40]. Fishmeal inclusion differs per species because *P. monodon* is more carnivorous than *L. vannamei,* thus requiring higher protein contents in their diets (36–42% for *P. monodon* and 18–35% for *L. vannamei*) [41]. Therefore, we set baseline fishmeal inclusions at 20% for *L. vannamei* and 30% for *P. monodon*. In total, we developed 24 feed formulations for the two species [*L. vannamei* (LV) and *P. monodon* (PM)] and two scenarios [common-plant scenario (LV1, PM1) and alternative-plant scenario (LV2, PM2)]. Each combination of species and scenarios contained six feed formulations with intermediate steps of 20% fishmeal substitution by plant ingredients (Section 3.3; Table 1). For simplicity, we excluded the inclusion of animal by-products or novel ingredients in the feed formulations, as their use is often limited by consumer perceptions, availability, and price [2,8].

The first scenarios consisted of a "common-plant scenario", which was driven by economic incentives and included plant ingredients with the lowest possible price, while the second scenario "alternative-plant scenario" excluded economic incentives and included alternative plant ingredients suitable for fishmeal substitution based on their nutrient profile. The "common-plant scenario" used mainly soybean (*Glycine soja*) meal to substitute fishmeal, as this crop is widely available, economically attractive [2,11], and considered a nutritious plant ingredient with high levels of protein and balanced amino acids [6,10]. The alternative-plant scenario substituted fishmeal with ingredients such as pea (*Pisum sativum; Pisum arvense*) protein concentrate, rapeseed (*Brassica napus*) meal, corn (*Zea mays*) gluten meal, and corn (*Zea mays*) oil. In order to create this scenario, we adjusted the prices of the ingredients in the feed formulations to be relatively lower than both fish and soybean meals, as their inclusion is not driven by economic incentives as in the common-plant scenario. However, based on nutrient profiles and protein content, these ingredients showed potential to substitute significant proportions of fishmeal in aquafeed [10]. These scenarios combined provided a comprehensive range of suitable plant ingredient options as fishmeal substitutes that are within the inclusion range of contemporary feeds and inclusive of future trends in commercial shrimp diet formulations. Therefore, the limits for plant feed ingredient incorporation were carefully selected on this basis, and our rationale for trending from high fishmeal to low fishmeal emulated current practice in many countries farming shrimp. It should be noted that these formulations support optimum growth and development of both shrimp species with much supporting literature [42,43]. The twenty-four developed feed formulations per species and scenarios are included in the model and listed in Table 1 (Section 3.3).

In order to ensure reliability of the model, we compared and observed similarities with the prices of our developed feed formulations and the indicative prices per ton of feed in Asia ($700–1100), China ($450–800), India ($844–956), and the Philippines ($876–967) [41,44].

3.2. Resource Demand Values

The resource demand of the feed formulations was calculated for the most relevant marine and terrestrial resources used to produce and process feed ingredients. Feed mixing and extrusion practices are not included in the model because their application and respective resource demand in global aquafeed production is relatively unknown. These practices could be applied in either small scale feed mills, locally at aquaculture farms, or produced in large scale factories [45]. However, all these practices are applied in range of different aquafeed formulations with or without high inclusions of fishmeal. Therefore, including an estimation of resource demand for feed mixing and extrusion would introduce an unnecessary variable when looking at the resource trade-offs of fishmeal substitution by plant ingredients, as shrimp diets are compared with each other. Therefore, the variables used in the model are primarily focused on the production and processing phase of the aquafeed ingredients.

Some ingredients, meals, and concentrates are directly processed from crops with associated losses. Therefore, we introduce average yields (%) from crops in order to gain insight into the amount of raw materials/crops needed to produce a certain ingredient. The yields of crop from processed ingredients such as soybean, rapeseed meal, and pea protein concentrate are 80% [46], 53% [47], and 25% [48], respectively. This means, for example, that in order to make pea protein concentrate, four times the amount of pea needs to be produced, which has a significant impact on the resource demand of pea protein concentrate. Therefore, average yields of crops were included in the model to gain insight into the resource demand of crop ingredients typically used in aquafeeds.

Conversely, some ingredients such as corn gluten meal and corn oil are not the result of direct concentrate processing but, for example, derived from regular corn processing into gluten feed, gluten meal, oil, and starch using the wet milling process [10]. However, corn gluten meal (5.2%) and corn oil (3.4%) represent only a small share of the total output of the wet milling process [46]. This means that the amount of resources for corn production needs to be allocated to corn gluten meal and corn oil in order to gain insight in their respective resource demands relative to corn production. This was calculated by multiplying the fraction of each ingredient (relative to total mass of all final products) with the total resource demands of corn production. This methodology is commonly used in life cycle assessment of both physical products and energy content [49,50]. We preferred to apply resource allocation by end-product mass over allocation by economic value, as economic value tends to change over time and therefore would introduce a changing variable in the resource demand values dataset (Table 1). Allocation of crop ingredients was included in the model, and their respective resource demand values are listed in Table 1 (Section 3.3).

Water: Water demand for crop production and processing of ingredients is globally variable, and different types of water demand are distinguished, namely green, blue, and grey water. Green water footprint refers to consumed rainwater, blue water footprint refers to the consumed or evaporated volume of surface and groundwater, and grey water footprint takes the volume of freshwater into account that is needed to process and neutralize certain pollutants. The global average freshwater demand per feed ingredient was obtained from Chatvijitkul et al. [46]. The green, blue, and grey water demands for crop production and processing were obtained from Mekonnen & Hoekstra [51] from 1996 until 2005 and their totals compared (combined green, blue, and grey water demands) with the values described in Chatvijitkul et al. [46] in order to verify their reliability. The total water footprint per hectare for wheat *(Triticum aestivum; Triticum durum; Triticum spelta)*, soybean, corn oil, and rapeseed were presented in Chatvijitkul et al. [46]. Additionally, the total water demand for corn gluten meal and processing of fish oil and fishmeal were obtained from Chatvijitkul et al. [46] based on estimates and FAO data [52]. Water demand (green, blue, and grey) for corn gluten meal was calculated by combining water demand for corn production [51] with resource allocation by end-product mass while adding up the estimated water demand (80 m^3/MT) for processing [46]. These resource demand values per ingredient were included in the model and are listed in Table 1 (Section 3.3).

In order to ensure the reliability of the model, water demand totals of the developed feed formulations for *L. vannamei* and *P. monodon* (baseline fishmeal inclusion, scenario common-plant) were compared with the resource demands described in Chatvijitkul et al. [46] of 819–1666 and 809–1542 (m^3/MT). The model results for the baselines fit well in these ranges.

Land: Crop yields influence the area of land needed to produce feed ingredients. We selected the top five global producers for wheat, soybean, rapeseed, and pea based on Table 1 from Fry et al. [14], as these producers dominate the global market (>50%) and are therefore the most likely producers of the ingredients necessary for the plant-based aquafeed. FAO data was obtained through the Factfish research platform [53], and we calculated the average land requirement (ha/MT) over a period from 2007 until 2016 for each of the top five global producers per crop ingredient. Subsequently, the five average land requirements per ingredient were combined with the global production share of each producer to calculate the global weighted average land requirement per ingredient. Global weighted average land requirement per ingredient is defined as mean and listed in Table 1 (Section 3.3). However, as land demand differs among the top five producers per ingredient, range bars in the graphs were used to establish a likely range of land demand required for the combination of ingredients in the feed formulations depending on the source locations of the ingredients. The range of land demand per ingredient based on the top five producing countries was entered in the model and can be found in Table 1 (Section 3.3).

To ensure the reliability of the model, the global average land requirement (ha/MT) from Chatvijitkul et al. [46] were compared to the range (min-max) of the average land requirement (2007–2016) for soybean, corn, wheat, and rapeseed of the top five producing countries. Additionally, we compared the model results (baseline fishmeal inclusion, scenario common-plant) with the ranges in land demand for shrimp feed for *L. vannamei* and *P. monodon* (0.115–0.352 and 0.187–0.314 ha/MT, respectively) from the paper of Chatvijitkul et al. [46]. The model results for the baselines fit well in these ranges.

Nitrogen and phosphorus: As fertilizer use such as nitrogen and phosphorus differs globally, we used the values of the fertilizer application per hectare from the top five global producers of the main crops used in aquafeed. First, the weighted average of fertilizer application in kilogram per hectare was calculated for each of the top five producing countries for soybean, rapeseed, and corn. We used fertilizer application data from 2001 until 2010 [54]. The global average fertilizer application for pea was obtained from FAO [55]. While soybean and pea are capable of fixing atmospheric nitrogen, FAO [55,56] recommends adding nitrogen for the early growth phase. Because of this, a value for added nitrogen for both soybean and pea was included in the model. Nitrogen and fertilizer application ranges for wheat was calculated based on data from The World NPK model [57], which shows fertilizer application rates per country (2007–2008). The ranges (min-max) for the top five producing countries for nitrogen and phosphorus application per crop ingredient were compared to the global average phosphorus and nitrogen rates per hectare to assess the reliability of data for soybean [56], corn [46,58], pea [55], and wheat [59]. Additionally, the global average fertilizer application from the World NPK model was used to validate the ranges of the data for soybean, corn, and rapeseed [57].

We chose to compare the resource demands of the different diets per metric ton (MT), and therefore a conversion from fertilizer application rates per hectare to fertilizer demand (kg) per metric ton (MT) of crop production was required. Therefore, the fertilizer application (kg/ha) was multiplied with the land requirement (ha/MT) ranges per ingredient in order to gain insight into the range of fertilizer demand (kg) per metric ton (MT) of shrimp feed. As phosphorus and nitrogen application differs among the top five producers per ingredient, range bars in the graphs were used to establish a likely range of phosphorus and nitrogen demand (kg/MT) required for the combination of ingredients in the feed formulations depending on the source locations of ingredients. The range of fertilizer demands per ingredient based on the top five producing countries was entered in the model and can be found in Table 1 (Section 3.3).

A comparison with the paper of Chatvijitkul et al. [46] was made in order to check the reliability of the conversion from fertilizer application in kilogram per hectare (kg/ha) to fertilizer demand (kg) per metric ton (MT) of crop ingredient production. Therefore, we compared the model results (baseline fishmeal inclusion, scenario common-plant) with the resource demand ranges of the diets of *L. vannamei* and *P. monodon*: 3.93–13.39 and 3.97–11.12 (kg/MT) for nitrogen, 1.29–3.54 and 2.13–5.01 (kg/MT) for phosphorus, respectively, described in Chatvijitkul et al. [46]. Higher values of phosphorus and nitrogen were observed in the analysis compared to the resource range from Chatvijitkul et al. [46] as a result of the exclusion of the use of animal by-products in the model and a different approach to the calculation of nitrogen and phosphorus demand values and resource allocation.

Fisheries: The demand for wild caught or so-called forage, reduction, or feed fisheries needed to produce both fishmeal and fish oil differs globally depending on the species, size, and season [12,23] and the inclusion of by-products (discards, trimmings, and offal from fishery processing) [7]. We acknowledge that fishmeal and fish oil production are inseparable and that the need for forage fish by the shrimp industry is mainly driven by fishmeal demand, while the need for forage fish for salmon feed is mainly driven by the demand for fish oil [6,23,60]. Applying the methodology of Jackson [60] would be more accurate from a global perspective in terms of fish demand because it calculates the need for marine ingredients for a combination of different aquaculture production and species with different fishmeal and fish oil demands. This means that, for example, a surplus of fishmeal from salmon feed production could be used for the shrimp industry [60]. However, the method of Jackson (2009) [60] has been criticized by Kaushik and Troell [61], who state that the addition of both the fishmeal and fish oil yields in the denominator is "somewhat questionable both from arithmetic and from a nutritional point of view". Nevertheless, we only consider the shrimp industry in this study and calculated the demand for fish to produce fishmeal and fish oil separately. Therefore, this oversimplification may not allow for the dual sourcing of fish for each component and could result in an overestimation of the need for fish resources but is considered a practical scenario given the current ratios advocated in the literature [7]. Therefore, global fishmeal and fish oil production statistics were obtained from scientific literature [7]. This was incorporated in the model as the minimum, mean and maximum resource demand values, as shown in Table 1 (Section 3.3). These values establish a likely range of fish demand (MT_{fish}/MT_{feed}) required for the production of both fishmeal and fish oil in the feed formulations depending on the source of the ingredients.

In order to ensure reliability of the model, we compared our model results (baseline fishmeal inclusion) with the fish demand ranges of the diets of *L. vannamei* and *P. monodon*: 270–1350 and 585–1935 (kg/MT), respectively, described in Chatvijitkul et al. [46]. The model results for the baselines fit well in these ranges.

Table 1. Twenty-four feed formulations for two shrimp species [*L. vannamei* (LV) and *P. monodon* (PM)] and two scenarios [(1) common-plant: fishmeal substitution by common plant ingredients and (2) alternative-plant: fishmeal substitution by alternative plant ingredients]. Each set per species and scenario (LV1, LV2, PM1, PM2) contained six feed formulations with intermediate steps of 20% fishmeal substitution by plant ingredients from the baseline. Each feed formulation used a unique combination of ingredients and their respective resource (freshwater, land, phosphorus, nitrogen, and fish) demand values, which determines the total resource demand of the feed formulation.

	Price (€/MT) *	Fishmeal (%)	Fish oil (%)	Wheat Feed (%)	Soybean Meal Concentrate (%)	Rapeseed Meal Concentrate (%)	Pea Protein Concentrate (%)	Corn Gluten Meal ** (%)	Corn Oil ** (%)	Vitamin and Mineral Premix (%)
Scenario 1: Fishmeal substitution by common plant ingredients (common-plant scenario)										
L. vannamei (LV1)	754	20.0	2.0	72.8	0.0	-	-	2.0	0.7	1.0
	729	16.0	2.0	75.5	0.9	-	-	2.0	1.1	1.0
	720	12.0	2.0	73.7	6.3	-	-	2.0	1.5	1.0
	711	8.0	2.0	72.0	11.6	-	-	2.0	1.9	1.0
	701	4.0	2.0	70.3	16.9	-	-	2.0	2.2	1.0
	692	0.0	2.0	68.6	22.3	-	-	2.0	2.6	1.0
P. monodon (PM1)	858	30.0	0.0	47.4	13.1	-	-	5.0	1.0	2.0
	875	24.0	2.0	42.7	21.8	-	-	5.0	1.0	2.0
	857	18.0	2.0	41.0	29.5	-	-	5.0	1.0	2.0
	839	12.0	2.0	39.3	37.2	-	-	5.0	1.0	2.0
	821	6.0	2.0	37.5	45.0	-	-	5.0	1.0	2.0
	806	0.0	2.0	35.1	52.9	-	-	5.0	1.0	2.5
Scenario 2: Fishmeal substitution by alternative plant ingredients (alternative-plant scenario)										
L. vannamei (LV2)	675	20.0	2.0	14.2	-	40.5	9.2	10.0	2.0	1.0
	661	16.0	2.0	14.3	-	38.6	14.4	10.2	2.3	1.0
	647	12.0	2.0	14.3	-	37.0	19.5	10.5	2.5	1.0
	635	8.0	2.0	14.0	-	35.6	24.5	10.7	2.8	1.0
	626	4.0	2.0	11.1	-	36.0	27.8	13.5	3.2	1.0
	617	0.0	2.0	7.8	-	36.7	30.8	16.7	3.6	1.0
P. monodon (PM2)	741	30.0	0.0	34.0	-	7.7	13.5	10.4	1.0	2.3
	724	24.0	0.0	31.3	-	7.0	19.4	13.3	1.0	2.8
	710	18.0	0.0	26.5	-	7.9	24.0	18.0	1.0	3.4
	697	12.0	0.0	21.7	-	8.8	28.6	22.7	1.0	4.0
	683	6.0	0.0	16.9	-	9.7	33.2	27.4	1.0	4.6
	686	0.0	2.0	12.0	-	10.7	37.8	32.0	1.0	3.3
Resource demand values										
Freshwater (m^3/MT)	Green	-	-	1277.0	2397.0	837.0	2906.0	1101.2	1996.0	-
	Blue	100.0	100.0	342.0	83.0	114.0	66.0	174.2	171.0	100.0
	Grey	-	-	207.0	44.0	165.0	986.0	225.6	409.0	-
Land (ha/MT)	Min	-	-	0.2	0.4	0.5	0.8	0.1	0.1	-
	Mean	-	-	0.3	0.5	0.9	1.2	0.2	0.2	-
	Max	-	-	0.4	1.1	1.6	2.2	0.7	0.7	-
Nitrogen (kg/MT)	Min	-	-	8.8	1.4	62.8	25.2	15.0	15.0	-
	Mean	-	-	28.2	3.8	87.3	34.5	18.7	18.7	-
	Max	-	-	37.2	35.3	151.1	66.4	35.3	35.3	-
Phosphorus (kg/MT)	Min	-	-	3.5	5.5	14.5	33.5	1.4	1.4	-
	Mean	-	-	11.4	15.1	25.1	46.0	3.7	3.7	-
	Max	-	-	16.3	29.9	49.6	88.5	7.2	7.2	-
Fish (MT_{fish}/MT_{feed})	Min	4.4	10.0	-	-	-	-	-	-	-
	Mean	4.5	20.0	-	-	-	-	-	-	-
	Max	4.6	50.0	-	-	-	-	-	-	-

Ingredients (Cholesterol, Lecithin, DL-Methionine) excluded from analysis due to insufficient data on impact indicators. * Scenario 2 (alternative-plant) excluded soybean (meal concentrate) from the feed formulations by adjusting ingredient prices, and therefore these diets are not driven by economic incentives. ** Corn gluten meal and corn oil are extracted from corn (through wet milling process), and therefore resources originated from corn production were allocated based on allocation by end-product mass with the addition of blue water demand for processing.

3.3. Model Simulations and Runs

As introduced in Section 3.1, the model ran six feed formulations per species and scenario with intermediate fishmeal substitution by plant ingredients. A total of 24 feed formulations and their unique ingredient compositions and ranges in resource demand values (Table 1) should provide insight into the impact of fishmeal substitution on marine and terrestrial resources.

As introduced in Section 3.2, a shared common data set of multi-factorial resource demand was developed and used per ingredient for each feed formulation to account for the global variety of resource demands by crops and its derived ingredients (Table 1; Resource demand values). The range for land demand and fertilizer application per crop ingredient was based on data for the top five producing countries. Their incorporation in aquafeed shows a high probability and therefore calculates a reliable range in land and fertilizer demand for the production of each crop derived ingredient. This results in three resource demand simulations (min, mean, max) per feed formulation for each impact indicator [land, phosphorus, nitrogen, and (wild) fish]. Water demand also contains three resource demand simulations, but this is the result of categorization of type of global water use (green, blue, grey) based on global averages rather than the range of water demand of different countries. Fish demand also contains three resources demand simulations based on ranges of fish demand for fishmeal and fish oil production from scientific literature.

The following equation was used to calculate the range in resource demands (freshwater, land, phosphorus, nitrogen, and fish) of the combined ingredients in the feed formulation. For each ingredient, the fraction in the feed was multiplied with the specific resource demand, and the different ingredients impacts were summed. The resource demands were calculated per ton (MT) of feed.

$$TRD_{R,M,X,S,P} = \Sigma(F_{I,X,S,P} \times RD_{R,I,M}) \quad (1)$$

$\mathbf{TRD_{R,M,X,S,P}}$: Total Resource Demand of resource R [fish (MTfish/MTfeed), freshwater (m^3/MT), Land (ha/MT), phosphorus (kg/MT), or nitrogen (kg/MT)] for the indicator value M (Minimum, Mean, or Maximum) at fishmeal inclusion X (%) for species S (*L. vannamei*, *P. monodon*) in plant inclusion scenario P (1: common-plant or 2: alternative-plant)

$\mathbf{F_{I,X,S,P}}$: Fraction (%) of ingredient I at fishmeal inclusion X (%) for species S in scenario P.

$\mathbf{RD_{R,I,M}}$: Resource Demand on resource R of ingredient I for indicator value M.

4. Results

This study modeled different sets of shrimp diets in combination with a comprehensive multifactorial assessment of marine and terrestrial resource demand for agricultural crop production and processed ingredients. The resource implications [freshwater, land, nitrogen, phosphorus, and (wild) fish] as a result of incremental fishmeal substitution by plant ingredients are presented in the following sections. The main results are shown in absolute and relative numbers, which puts emphasis on the relative (%) change in resource demand as a result of complete fishmeal substitution with plant ingredients, highlighting the trade-offs between marine and terrestrial resources.

4.1. Freshwater Demand

Substitution of fishmeal by plant ingredients directly increased the pressure on freshwater resources, for both species and scenarios (Figure 1). As a result of a complete fishmeal substitution, freshwater demand increased strongest for LV2 approximately by 63% from 1298 m^3/MT to 2118 m^3/MT. PM1 and PM2 showed a respective increase of 57% (1354–2119 m^3/MT) and 62% (1485–2402 m^3/MT), while the freshwater demand for LV1 increased by 37% (1401–1915 m^3/MT). The share of green water demand in the common-plant scenario increased from 69% to 77% for LV1, with respective increases of 75% to 86% for PM1. In the alternative-plant scenario, this increase in green water demand was lower, with an increase of two percentage points for both LV2 and PM2. However, in this scenario, an increasing share of grey water was observed of three percentage points for LV2 and four percentage points for PM2.

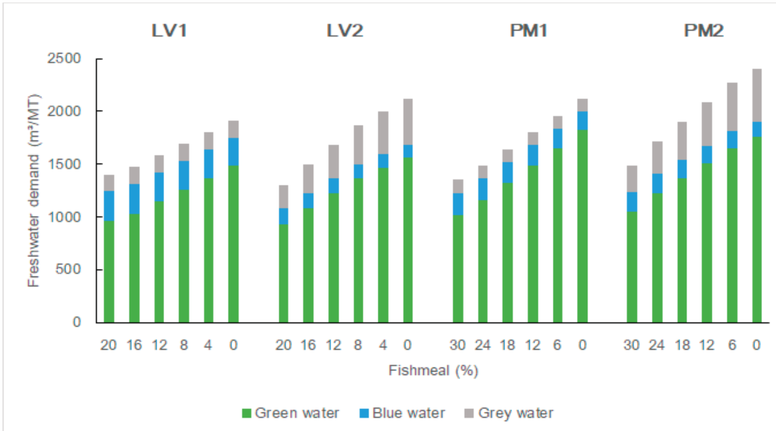

Figure 1. Freshwater demand (m^3/MT) for the baselines and five substitution levels in two scenarios and for two species. Green bar indicates consumed rainwater, blue bar indicates consumed or evaporated volume of surface and groundwater (irrigation), and grey bar indicates freshwater needed to process and neutralize pollutants.

4.2. Land Demand

Mean land demand in a 0% fishmeal inclusion for common-plant scenario for both species was slightly more than half that of the alternative-plant scenario, approximately 0.33 (LV1) and 0.38 (PM1) ha/MT and 0.76 (LV2) and 0.65 (PM2) ha/MT (Figure 2). Land demand for crop production increased in all scenarios with significant differences between LV and PM. Average land demand rose strongest for PM from 0.23 ha/MT to 0.38 ha/MT (67%) in the common-plant scenario and from 0.36 ha/MT to 0.65 ha/MT (81%) in the alternative-plant scenario. Although land demand was highest for LV2 at 0% fishmeal inclusion (0.76 ha/MT), the increase in mean land demand was relatively lower for LV in both scenarios with 42% (LV1) and 40% (LV2).

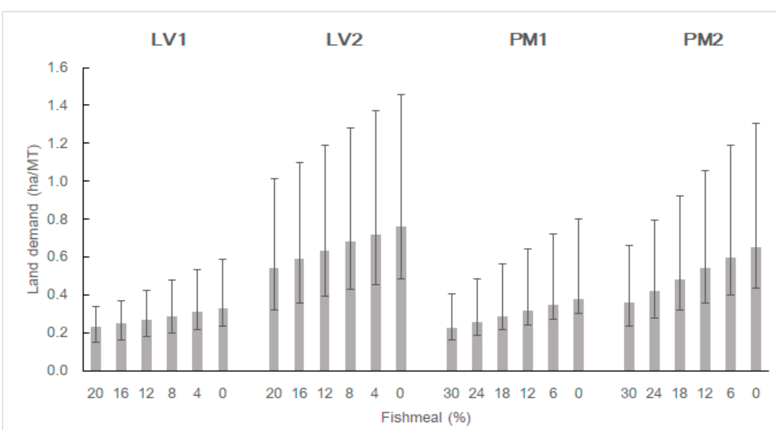

Figure 2. Minimum, mean, and maximum land demand (ha/MT) for the baselines and five substitution levels in two scenarios and for two species. The y-axis represents the global mean land demand, and the bars indicate the range (min/max) in land demand of a combination of ingredients in the feed formulations.

4.3. Nitrogen Demand

Mean nitrogen demand in a 0% fishmeal inclusion for the common-plant scenario was relatively lower compared to the alternative-plant scenario, approximately 21 kg/MT (LV1) and 13 kg/MT (PM1) and 49 kg/MT (LV2) and 32 kg/MT (PM2) (Figure 3). Mean nitrogen demand increased in the alternative-plant scenario by 9% (45–49 kg/MT) and 39% (23–32 kg/MT) for LV2 and PM2, respectively. On the other hand, nitrogen in the common-plant scenario showed no change (+0.1%) for LV1 and a decrease of 12% in PM1. In general, considering the variability in the model estimates, nitrogen demand was relatively stable in the common-plant scenario and showed an increase in demand in the alternative-plant scenario.

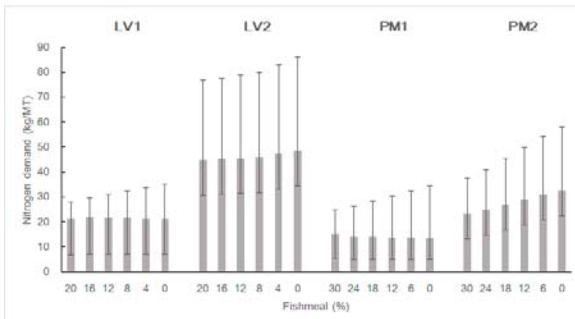

Figure 3. Minimum, mean, and maximum nitrogen demand (kg/MT) for the baselines and five substitution levels in two scenarios and for two species. The y-axis represents the global mean nitrogen demand, while the bars indicate the range (min/max) in nitrogen demand of a combination of ingredients in the feed formulations.

4.4. Phosphorus Demand

Mean phosphorus in a 0% fishmeal inclusion for the common-plant scenario was relatively lower compared to the alternative-plant scenario, approximately 11 kg/MT (LV1) and 12 kg/MT (PM1) and 25 kg/MT (LV2) and 23 kg/MT (PM2) (Figure 4). Mean phosphorus demand rose strongest (approximately 83%) for PM2 with an increase from 12 kg/MT to 23 kg/MT. Minimum phosphorus demand showed an increase in the common-plant scenario for both shrimp species, from 2.6 kg/MT to 3.7 kg/MT for LV1 and 2.5 kg/MT to 4.2 kg/MT for PM1.

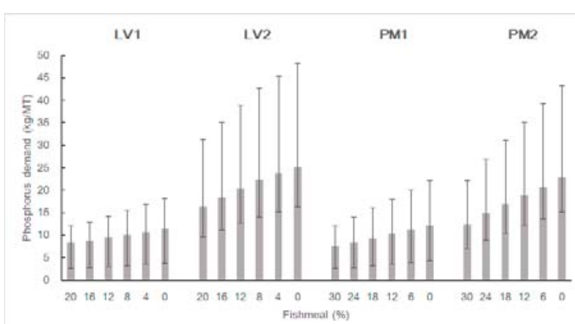

Figure 4. Minimum, mean, and maximum phosphorus demand (kg/MT) for the baselines and five substitution levels in two scenarios and for two species. The y-axis represents the global mean phosphorus demand, while the bars indicate the range (min/max) in phosphorus demand of a combination of ingredients in the feed formulations.

4.5. Fish Demand

Demand of fish declined by approximately 70% to a value of 0.4 MT_{fish}/MT_{feed} for both species and scenarios (Figure 5). Initial fish demand for both shrimp species were quite similar, even with a difference in initial fishmeal inclusions. LV showed in both scenarios a linear decrease, while PM1 under the common-plant scenario showed an increase from 1.35 until 1.48 MT_{fish}/MT_{feed} (+9.6%) for fishmeal inclusions between 30% and 24%. On the other hand, PM2 under the alternative-plant scenario showed a decrease in the demand of fish with the exception of fishmeal inclusions between 6% and 0%, where an increase in fish from 0.27 until 0.4 MT_{fish}/MT_{feed} was observed. Additionally, the model predicted a large variability in fish demand among the different feed formulations.

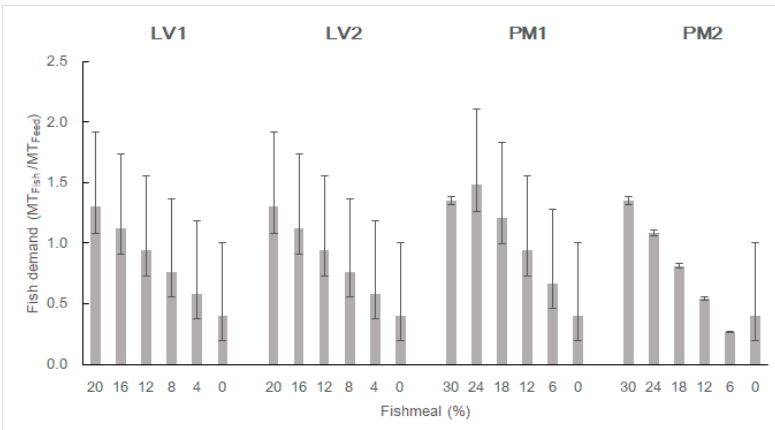

Figure 5. Minimum, mean, and maximum fish demand (MT_{fish}/MT_{feed}) for the baselines and five substitution levels in two scenarios and for two species. The y-axis represents the global mean fish demand, while the bars indicate the range in fish demand for the inclusion of fish oil and fishmeal.

5. Discussion

5.1. The Sustainability Conundrum of Fishmeal Substitution

There is an obvious global strategy to find alternatives to the use of finite fish resources in the formulation of aquafeeds by using mainly plant ingredients. Our results show that although this strategy serves to mitigate marine protein and oil dependency, when used as a sole substitute, it shifts pressure to terrestrial resources. The modeling results show the intensity of the added pressure on freshwater, land, and fertilizer, highlighting a shift in pressures in the longer term for using higher inclusions of plant ingredients in aquafeed. The continuing trend of increased inclusion of terrestrial plant-based ingredients may lead to competition for land, causing social and environmental conflicts, which may in turn affect the resilience of the global food system [14,16,17].

Increasing production of terrestrial plant-based ingredients requires land, fertilizer, and freshwater resources [13–15]. On a species level, freshwater demand at 0% fishmeal inclusion (all fishmeal was substituted by plant-based ingredients) was relatively higher for *P. monodon* in both scenarios compared to *L. vannamei* as a result of the higher inclusion of water demanding crop ingredients (soybean meal, rapeseed meal, and pea protein concentrate). This clearly indicates that fishmeal substitution for the carnivorous *P. monodon* requires more terrestrial resources to meet nutritional requirements. According to Chatvijitkul et al. [46], resource demand range for *L. vannamei* and *P. monodon* feed is relatively similar with the exception of (wild) fish use for *P. monodon*. The total freshwater footprint of our model for *L. vannamei* under both scenarios (fishmeal 20%) was very similar compared to *P. monodon* (fishmeal 24%), both close to 1600 m^3/MT. This value is close to that shown by Pahlow et al. [15] for *P. monodon* and *L. vannamei* at a fishmeal inclusion of approximately 25%. This paper shows that on a species level, while fishmeal inclusion in the diet of *P. monodon* declined from 33.7% to 6%, total water footprint increased from approximately 1500 m^3/MT to 2100 m^3/MT, and a change in ratio of green, blue, and grey water footprint occurred, which shows similarities with our model results. This is likely because larger inclusion shares of terrestrial crop ingredients could increase the water footprint [15]. On a scenario level, the observed increase in the share of grey water in the alternative-plant scenario can be explained by the inclusion of fertilizer demanding crops for the required ingredients, such as rapeseed meal concentrate, pea protein concentrate, corn gluten meal, and corn oil in comparison to soybean and wheat in the common-plant scenario. Contrarily, blue water (irrigation) in the alternative-plant scenario reduces due to high inclusion rate of pea protein concentrate.

According to Boissy et al. [13], land use is specifically affected by plant ingredient substitutions in salmon and trout feeds. On a species level, the large differences in mean land demand between *L. vannamei* and *P. monodon* in both scenarios is caused by the higher inclusions of soybean meal, pea protein concentrate, and corn gluten, and their relatively higher land use compared to other aquafeed ingredients (Table 1). According to Pelletier et al. [8] soy production requires more land compared to corn and wheat. The stronger increase in mean land demand (ha/MT) of LV1 (0.33) to LV2 (0.76) compared to PM1 (0.38) to PM2 (0.65) is likely caused by relatively lower inclusion (16.7%) of corn gluten meal in LV2 compared to 32% in PM2. Corn gluten meal requires relatively less land (0.2 ha/MT) compared to rapeseed meal (0.9 ha/MT), which has a higher inclusion (36.7%) in LV2 compared to 10.7% in PM2 (Table 1). On a scenario level, it is obvious that land demand is significantly higher in the alternative-plant scenario as a result of the inclusion of crops with a higher land demand such as rapeseed, pea, and corn compared to soybean and wheat in the common-plant scenario. The modeled range in land demand is caused by variable source locations and consequently land use demands of soybean, rapeseed, pea, and corn compared to wheat.

Boissy et al. [13] highlighted that low fishmeal diets (for salmon and trout) have higher terrestrial ecotoxicity values compared to high fishmeal diets due to fertilizer and pesticide use, especially for rapeseed. This explains the high nitrogen demand for the alternative-plant scenario, especially for *L. vannamei* containing the highest inclusion of rapeseed in the feed formulation. Conversely, the diets for *P. monodon* require less nitrogen because of lower inclusion of wheat and rapeseed compared to *L. vannamei.* In the common-plant scenario, fishmeal and wheat is substituted by soybean, which requires relatively less nitrogen but more phosphorus, which shows similarities with other published crop resource demands [46]. Therefore, a correlation between a relatively stable nitrogen demand in the common-plant scenario and an increase in phosphorus is observed. The alternative-plant scenario is overall higher in phosphorus demand due the inclusion of rapeseed meal concentrate and pea protein concentrate, both requiring relatively more phosphorus compared to the other aquafeed ingredients in the feed formulations (Table 1). This also explains the stronger rise in phosphorus requirements for *P. monodon* in both scenarios due the high inclusion of pea protein concentrate and soybean meal concentrate to meet nutritional requirements. The variability in phosphorus demand is dependent on the source of soybean, rapeseed, pea, corn, and wheat (Table 1). However, it is important to take into account that agricultural production in some parts of the tropics requires higher phosphorus application due the phosphorus fixing characteristics of the soil (30). In our model, this is especially clear for the phosphorus application rates for soybean sourced from Brazil (29% of global production). Consequently, the inclusion of crops and derived ingredients from these sources could increase the resource demand of aquafeed.

Complex dietary requirements of aquatic species may prevent complete substitution of fishmeal and fish oil by plant-based ingredients (10). The production of fish oil requires more fish compared to fishmeal (7), which explains the increasing demand for fish in PM1 (24% fishmeal) and PM2 (0% fishmeal), as fish oil inclusions in the feed formulations increased from 0% until 2%. This also explains the demand of 0.4 MT_{fish}/MT_{feed} in a 0% fishmeal inclusion for both species and scenarios, which is caused by the inclusion of 2% fish oil. However, fish demand for fish oil shows much greater variability for fish demand compared to fishmeal (7). Therefore, the low variability in fish demand in some of the formulations of *P. monodon* can be explained by the absence of fish oil.

5.2. Nutritional Limitations of Plant Ingredients in Aquafeeds

Marine ingredients contain a suitable nutritional profile of amino acids, fatty acids, phospholipids, trace elements, nucleotides, vitamins, and other biologically beneficial compounds [5,8,9]. Although some terrestrial plant ingredients are economically attractive, these may also contain anti-nutritional factors (ANFs) [8]. Additionally, their oils may not deliver the entire balanced essential fatty acids (Omega-3s) of the long-chain polyunsaturated fatty acids (LC-PUFAs) found in marine lipids. This can affect the growth of crustaceans more profoundly, principally due to a lower ability to digest and absorb lipids, especially at their developmental stages [62]. However, the development of exogenous enzymes as feed additives offer significant advantages in augmenting digestibility of non-starch polysaccharides (dietary fiber), protein, and release of macro-elements such as phosphorus from P bound phytate in ingredients like soya bean meal [63–66]. Dietary protease results in a better nutrient utilization, which benefits the immune system of shrimp [67]. Other feed additives meet nutritional requirements, such as the enzyme phytase by improving phosphorus and mineral availability from plant ingredients [10]. Additionally, genetic selection and modification shows potential to modify LC Omega-3 oils in terrestrial plants and to modify the dietary requirements of aquaculture species [6,7,10].

5.3. Limitations of the Model

Feed formulations are variable and mainly based on dietary requirements and ingredient price, which could be influenced by, for example, availability, trade, fuel costs, and competition for resources [44]. Missing data in the geographic origin of crops [13–15], variation in country-level crop yields (Chatvijitkul et al.; table 2 [46]), resource demand of (future) agricultural production, processing techniques and yields, and resource allocation result in a range of resource demands for aquafeed ingredients [8,15,46]. Additionally, it must be noted that the skewed range towards high resource demand for land, nitrogen, and phosphorus is often caused by countries with a much higher resource demand compared to the mean while representing a relatively small share (<10%) in global crop production. Additionally, the reliability of the data remains a point of contention, as data reported by governmental organizations such as FAO can be inaccurate (because of delivery from the member countries [68]), but they are the best available data collected in a relatively systematic way. To account for data limitations, we developed and used a shared common data set of multi-factorial resource demand per ingredient (Table 1), and this was applied to each of the feed formulations regardless of the fishmeal inclusion level. Consequently, the differences in resource demand per feed formulation are mainly caused by the variation in inclusion level of the ingredients selected. In this manner, relative outputs are generated by the application of our model that are independent of resource demands. Although our model encompasses reliable feed formulations used by the industry, it is mainly dependent on secondary data and therefore cannot be tested using conventional statistical methods.

Increase in plant ingredient production could potentially lead to socio-economic benefits, such as an increase in farmers' income and rural employment. Additionally, the production and processing of aquafeed ingredients could also generate side streams, which could be useful for other (food and feed) industries and reducing the need for additional resources. However, the model does not take this into account, as the shrimp industry is considered independently in this research.

6. Conclusions

Aquaculture is one of the fastest growing food industries with increasing feed use for high-value species such as shrimp. This sector is becoming a major player with opportunities for land-based production and therefore increasing the pressure on valuable marine and terrestrial resources. Aquaculture, and in particular the shrimp industry, is one of the dominant consumers of the global fishmeal supply, which is increasingly substituted by mainly plant ingredients. This increases the dependency and competition for agricultural crops from a terrestrial system and its essential resources, which are already under pressure to meet global demand for food, feed, biofuels, and biobased materials.

Our model highlights the need for a paradigm shift in the definition of sustainable shrimp feed by presenting quantitative data on the consequences relating to sea-land linkages as a result of the substitution of fishmeal with terrestrial ingredients based on current resource demands. Our study has clearly demonstrated that complete fishmeal substitution by plant ingredients could lead to an increasing demand for freshwater (up to 63%), land (up to 81%), and phosphorus (up to 83%). These are significant increases, as only a share of 20–30% of the feed is actually substituted. This is mainly caused by the inclusion of resource intensive crops and their derived ingredients to meet nutritional requirements, such as soybean meal concentrate, rapeseed meal concentrate, pea protein concentrate, and corn gluten meal. While aquafeed consumes approximately 4% of the global feed crops and therefore consumes a small share of the agricultural resources (such as water and land), a shift from fishmeal to plant ingredients should not be taken for granted as a sustainable solution to meeting a rapidly expanding (shrimp) aquaculture industry. The additional pressure on crucial terrestrial resources inflicted by the rapidly growing aquaculture sector may become more obvious over the next decades.

Although fishmeal can be used more strategically in various aquafeed formulations (IFFO, personal communication, 2018), there is a need for more innovation to optimize its value in relation to alternative ingredients. Strategic management and utilization of fish by-products shows potential for higher resource use efficiency of valuable marine resources [69]. Additionally, improvement of feed conversion ratios [2], side streams up to 30–40% of the global food system [28], and novel protein sources (microbial biomass [70], insects [71], yeast, microalgae [6], macroalgae [72], and macrophytes) might allow acceptable solutions to supplement high quality fishmeal [8,9,44]. On the other hand, farming up the food chain [Integrated Multi-Trophic Aquaculture (IMTA), biofloc aquaculture systems and aquamimicry] often require less biological resources and far less to almost no aquafeed input [73,74]. This must be factored into future models and scenarios in combination with broader sustainability considerations and indicators, as described in Valenti et al. [75], and nutritional value of aquaculture products.

While the paper is focused on shrimp farming, the model may be equally applicable to other intensively farmed species (for example, freshwater and marine finfish) with similar scenarios of marine and terrestrial feed ingredient requirements using reliable datasets and information platforms. However, more data on the origin and resource demand of ingredients are required in order to gain accurate insight into the optimal use of marine and terrestrial resources. This would enable the shrimp farming industry to operate and contribute in a sustainable manner to global food security and the economy, providing the much needed high nutritionally valuable seafood. This is crucial if we seek to prevent hunger and poverty in developing countries and elsewhere and if people wish to continue consuming healthy, nutritious seafood. Understanding the real impact of feed production would be a starting point for the realistic pricing of aquafeed and would create awareness of the impact of our current choices on future generations. Contrary to the current situation, such a strategy will create sustainable feeds that will contribute to the SDGs of the UN.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/11/4/1212/s1, The excel model and data used to perform this work can be found in the supplementary material.

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Willingness-to-Pay for Sustainable Aquaculture Products: Evidence from Korean Red Seabream Aquaculture

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Abstract: A New Ecological Paradigm scale was used as a measurement tool to determine consumer perception of the environment through the context of red seabream (*Pagrus major*) aquaculture and the use of copper-alloy nets. To identify the underlying dimension of consumer perception, exploratory factor analysis was conducted, which showed that consumer perception comprised two dimensions—nature and balance, and human dominance—yielding two indicators as independent variables for a contingent valuation method estimation. The estimation results indicate that demographic variables and one consumer perception variable (i.e., the human dominance indicator) are insignificant. However, the economic variable, one consumer perception variable (i.e., nature and balance), and seafood preference are significant. Finally, willingness-to-pay was estimated for sustainable aquaculture products by comparing the mean willingness-to-pay within New Ecological Paradigm-level groups.

Keywords: contingent valuation method; double-bounded dichotomous choice; environmental economics; environmental psychology; New Ecological Paradigm; seafood preference; copper-alloy nets

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1. Introduction

Demand for sustainable aquaculture is growing [1–3]; in particular, an aquaculture system that maintains economic, environmental, and social sustainability [4]. With increasing awareness of its value for the environment, sustainable aquaculture is gaining greater interest among fish farmers, as well as consumers. In 2010, the World Wide Fund for Nature (WWF) initiated the Aquaculture Stewardship Council (ASC) to promote sustainable aquaculture [5]. The council has developed ASC farm standards for certifying sustainable and responsible aquaculture. ASC's consumer label intends to support sustainable aquaculture through a market mechanism that would enable consumers to identify responsibly farmed seafood, thereby generating a price premium for ASC-labeled products. The price premium can then be assessed by consumer willingness-to-pay (WTP) for sustainable aquaculture products.

Consumer WTP for sustainable aquaculture is likely to cause a chain reaction; for example, higher consumer value for sustainable aquaculture products increases demand from retailers and intermediaries, which subsequently incentivizes fish farmers to move toward sustainable aquaculture. Moving toward sustainable aquaculture is especially critical to cage farming enterprises that often produce unfavorable environmental conditions. In marine cage aquaculture for finfish species, a typical environmental issue involves managing the fouling in cage nets. Fouling is inevitable in fish culture, and mechanical and chemical measures are employed to handle it [6]. The main components of an antifouling agent are copper and zinc powders, which remove organisms that have adhered to cage nets [6]. However, the properties of antifouling agents can adversely affect the marine environment. The concentration of metallic elements in sediment near fish farming sites, for instance, has attracted public concern over environmental sustainability. One way to alleviate this concern and eliminate the metallic elements is by using copper-alloy aquaculture nets [7]. These nets do not require antifouling paint treatment, and the used net can be recycled into new nets. However, it is difficult for a producer to use copper-alloy nets in aquaculture due to the higher cost. The cost difference between using copper alloy and nylon nets could be interpreted as the cost in maintaining environmental sustainability in aquaculture. While public funding might be an option, the price premium from an eco-friendly consumer label could resolve cost issues. Given that conventional aquaculture is the dominant system, sustainable aquaculture using copper-alloy nets could lose its place in the industry without establishing consumer support.

The Korean government recently launched a research and development program for the adoption of copper-alloy nets in red seabream (*Pagrus major*) aquaculture. Red seabream is a popular sushi ingredient in South Korea, where its annual aquaculture production reaches an average of 5400 tons (Table 1). The government has installed a testing cage in a red seabream aquaculture farm to determine the feasibility of introducing copper-alloy nets in marine cage culture.

Table 1. Production of red seabream in South Korea (unit: tons).

	Total	Capture Fisheries				Aquaculture		
		Sub-Total	Live	Fresh	Frozen	Sub-Total	Live	Fresh
2008	8728	1304	577	555	172	7424	7424	-
2009	11,090	1864	732	948	184	9226	9224	2
2010	8712	2412	756	1483	173	6300	6300	-
2011	5988	2490	820	1440	230	3498	3492	6
2012	5468	2598	766	1587	245	2870	2847	23
2013	5044	2289	534	1582	173	2755	2755	-
2014	6235	2169	423	1577	168	4066	4066	-
2015	8231	2062	386	1613	63	6169	6165	4
2016	7390	2069	430	1623	16	5321	5321	-
2017	8708	1902	419	1458	25	6806	6806	-

Source: Statistics Korea http://www.index.go.kr/potal/main/EachDtlPageDetail.do?idx_cd=2748.

This study examines consumer perception of the environment and consumer WTP for sustainable aquaculture products when using copper-alloy nets. Specifically, the present research investigates consumer attitudes toward a pro-ecological worldview using the New Ecological Paradigm (NEP) scale. The results of the NEP measurements are used to conduct a double-bounded contingent valuation method (CVM) to estimate WTP for red seabream. The study also investigates which factors affect consumer value judgment using this analytical process.

The present findings contribute to promotion of sustainable aquaculture and seafood marketing as the CVM results could provide crucial information about the price premium of sustainable aquaculture products, as well as factors influencing WTP. Making this practical information available will enable marketers and policy developers to understand consumer purchasing behavior and value, thereby priming the transition from conventional to sustainable aquaculture.

2. Literature Review

2.1. New Ecological Paradigm

Support for sustainable aquaculture is growing stronger with the recognition of environmental sustainability. The ASC and the Marine Stewardship Council (MSC) are fishery certification schemes that reflect the value of ecology and environmental sustainability. The introduction of such schemes would be successful as long as consumers actively participate in and support the scheme because research shows that consumer perception eventually leads to support [8–12].

Certain psychological items can be used to measure consumer perception. For example, the NEP scale mentioned earlier and first proposed by Dunlap and Van Liere [13] is one of the most representative measurement tools for environmental awareness [14,15]. It initially comprised 12 measurement items; after 20 years of development, Dunlap et al. presented a refined version of this scale [14]. The revised NEP scale now comprises 15 measurement items including three dimensions: limitations of growth, nature and balance, and human dominance.

Scholars have used the NEP scale as a research tool to measure environmental awareness in various fields, such as education, environment, and marketing [16]. It has also been used to examine the effects of human environmental awareness on behavior and value judgment. For example, Park et al. integrated the NEP measurement scale and decision-making theory to analyze the influence of environmental awareness on travelers' pro-environmental behavior [17].

The theory of planned behavior is a fundamental theory concerning human behavior and the decision-making process, which argues that human attitude, subjective norms, and perceived behavior control determine human behavior [8,18–20]. Fielding [8] states that environmental awareness is more likely to affect human attitude, which consequently affects human behavior. Kotchen and Reiling examined relationships between environmental attitudes and value for endangered species, as well as motivations for contingent valuation [21]. The authors integrated the attitude–behavior theory and economic valuation technique, and used the NEP scale as a proxy for attitude concerning the environment. This allowed them to estimate economic values of endangered species, such as falcons and shortnose sturgeons.

2.2. Contingent Valuation Method

The purchasing behavior and price premium of a product could reflect consumer value [22–24]. If NEP is a measure of environmental awareness, consumer value for environmental sustainability can be measured by examining the relationship between NEP and consumer WTP.

The CVM enables individuals to evaluate value for a hypothetical situation in which researchers have limited information on the real market. In CVM analysis, researchers develop a survey for a hypothetical market and ask a survey participant to make an economic decision (i.e., to buy or not to buy). Many academic studies have used CVM as an analytical tool. For example, in the environmental research field, it has been traditionally used for measuring non-market value for the environment [25,26]. It has seen application even in fields of outdoor recreation and tourism [27–29]. In food marketing research, CVM has been used to estimate consumer WTP for organic food and environmentally friendly products [30–32].

The theoretical background of CVM is choice modeling, which can be used in revealed preference and stated preference studies [33]. CVM itself is a stated preference study method, which assumes that an individual makes an economic decision to choose product A over product B to maximize utility. This selection is a function of utility maximization in repeated selection opportunities. The choices made by individuals under experimental conditions are used for estimating values in a hypothetical situation.

In a CVM survey, participants are asked to indicate their WTP for a good or service by answering whether or not they accept the offer given. Another way to determine WTP involves two-stage answers. At each stage, the suggested amount of money is different, similar to auction bidding. The survey participants must answer "Yes" or "No" to the stated prices that have been increased or decreased. This is called a double-bounded dichotomous choice CVM.

3. Methods

3.1. Sample

A major online survey company in South Korea recruited the survey participants for this study. The survey panel is designed to represent typical demographic variables of the Korean population, reflected in gender, age group, income level, and location. The participants were asked to respond to the survey questions based on their WTP for a sustainable aquaculture product, such as farmed red seabream. The research company distributed 2712 survey questionnaires to the panel members; 1000 usable responses were obtained (response rate of 36.8%).

3.2. Survey Instrument

The survey questionnaire comprises three parts: 1) attitude toward the environment; 2) WTP for sustainable aquaculture products; and 3) demographic information.

The current research used the NEP scale to measure the respondents' attitudes. This scale has evolved over two decades, and among its variants, the author selected the revised NEP scale [14]. It consists of 15 items to measure survey participants' perception and attitude (Table 2).

Table 2. A revised New Ecological Paradigm scale.

Item
A1. We are approaching the limit of the number of people Earth can support
A2. Humans have the right to modify the natural environment to suit their needs
A3. When humans interfere with nature, it often produces disastrous consequences
A4. Human ingenuity will insure that we do NOT make Earth unlivable
A5. Humans are severely abusing the environment
A6. Earth has plenty of natural resources if we just learn how to develop them
A7. Plants and animals have as much right as humans to exist
A8. The balance of nature is strong enough to cope with the impacts of modern industrial nations
A9. Despite our special abilities, humans are still subject to the laws of nature
A10. The so-called "ecological crisis" facing humankind has been greatly exaggerated
A11. Earth is like a spaceship with very limited room and resources
A12. Humans were meant to rule over the rest of nature
A13. The balance of nature is very delicate and easily upset
A14. Humans will eventually learn enough about how nature works to be able to control it
A15. If things continue on their present course, we will soon experience a major ecological catastrophe

Source: Dunlap et al. [14].

The survey respondents' WTP was measured by their responses to a suggested price for sustainable aquaculture products (i.e., farmed red seabream). The survey began with displayed text concerning aquaculture (Table 3). Next, a randomly selected amount was proposed for determining WTP for a sustainable aquaculture product (i.e., red seabream for sushi). The survey contained two preference questions that required a "Yes/No" response: one for the randomly selected amount of money, and another for the modified amount of money.

Table 3. Text in the survey questionnaire.

Displayed Text
"A variety of equipment are required for sea aquaculture (marine cage use). Among them, cage farming nets are essential equipment for protecting and raising fish. However, cage farming nets require effort to maintain cleanliness because organisms, such as barnacles and seaweed, attach themselves to the net. Water cannot circulate through sea cages to which organisms have adhered, creating an unhealthy environment for fish. A typical method of keeping farming nets clean is to coat them with antifouling agents. However, general antifouling agents (i.e., containing chemical ingredients) can cause environmental disturbances. The copper-alloy farming net is eco-friendly aquaculture equipment that can prevent the adherence of organisms without using antifouling agents. They can also be recycled after use. However, unlike ordinary cage farming nets, the copper-alloy fishing nets have high initial costs. To protect the environment and ensure food safety, consumer support for sustainable aquaculture is essential. This can be done by buying sustainable aquaculture products that have been produced using copper-alloy farming nets."

Note: The current market price for live red seabream is ~$30–35/kg.

3.3. Model

The double-bounded dichotomous-choice CVM analytically estimates WTP for sustainable aquaculture products. The author categorizes consumer responses into four types [34]. The first response type is "Yes/No," which the researcher denotes as $y_i^1 = 1$ and $y_i^2 = 0$. Its probability model is shown below:

$$\begin{aligned} \Pr(s,n) &= \Pr(t^1 \le WTP < t^2) \\ &= \Pr(t^1 \le z_i'\beta + u_i < t^2) \\ &= \Pr\left(\frac{t^1 - z_i'\beta}{\sigma} \le \frac{u_i}{\sigma} < \frac{t^2 - z_i'\beta}{\sigma}\right) \\ &= \Phi\left(\frac{t^2 - z_i'\beta}{\sigma}\right) - \Phi\left(\frac{t^1 - z_i'\beta}{\sigma}\right) \\ \Pr(s,n) &= \Phi\left(z_i'\frac{\beta}{\sigma} - \frac{t^1}{\sigma}\right) - \Phi\left(z_i'\frac{\beta}{\sigma} - \frac{t^2}{\sigma}\right) \end{aligned} \tag{1}$$

where Pr(s,n) represents the probability of an event that the survey participants accept the first offer (i.e., s = yes) and decline the next offer (i.e., n = no); t^1 and t^2 represent the suggested amount for the first and second offer respectively; z_i is a vector of explanatory variables and u_i is an error term.

The second response type is also "Yes/No," denoted as $y_i^1 = 1$ and $y_i^2 = 1$. Its probability model is shown below:

$$\begin{aligned} \Pr(s,s) &= \Pr(WTP > t^1,\ WTP \ge t^2) \\ &= \Pr(z_i'\beta + u_i > t^1,\ z_i'\beta + u_i \ge t^2) \end{aligned} \tag{2}$$

Equation (2) can be described based on Bayes' theorem, as shown below:

$$\begin{aligned} \Pr(s,s) &= \Pr\left(z_i'\beta + u_i > t^1 \middle| z_i'\beta + u_i \ge t^2\right) * \Pr\left(z_i'\beta + u_i \ge t^2\right) \\ \Pr(s,s) &= \Pr\left(u_i \ge t^2 - z_i'\beta\right) \\ &= 1 - \Phi\left(\frac{t^2 - z_i'\beta}{\sigma}\right) \\ \Pr(s,s) &= \Phi\left(z_i'\frac{\beta}{\sigma} - \frac{t^2}{\sigma}\right) \end{aligned} \tag{3}$$

The third response type is "Yes/No," denoted as $y_i^1 = 0$ and $y_i^2 = 1$. Its probability model is shown below:

$$\begin{aligned} \Pr(n,s) &= \Pr(t^2 \le WTP < t^1) \\ &= \Pr(t^2 \le z_i'\beta + u_i < t^1) \\ &= \Pr\left(\frac{t^2 - z_i'\beta}{\sigma} \le \frac{u_i}{\sigma} < \frac{t^1 - z_i'\beta}{\sigma}\right) \\ &= \Phi\left(\frac{t^1 - z_i'\beta}{\sigma}\right) - \Phi\left(\frac{t^2 - z_i'\beta}{\sigma}\right) \\ \Pr(n,s) &= \Phi\left(z_i'\frac{\beta}{\sigma} - \frac{t^2}{\sigma}\right) - \Phi\left(z_i'\frac{\beta}{\sigma} - \frac{t^1}{\sigma}\right) \end{aligned} \tag{4}$$

Finally, the fourth response type, "Yes/No," is denoted as $y_i^1 = 0$ and $y_i^2 = 0$. Its probability model is shown below:

$$\begin{aligned} \Pr(n,n) &= \Pr(WTP < t^1,\ WTP < t^2) \\ &= \Pr(z_i'\beta + u_i < t^2) \\ &= \Phi\left(\frac{t^2 - z_i'\beta}{\sigma}\right) \\ \Pr(n,n) &= 1 - \Phi\left(z_i'\frac{\beta}{\sigma} - \frac{t^2}{\sigma}\right) \end{aligned} \tag{5}$$

Using equations (1)–(5), the author derives the likelihood function for WTP estimation:

$$\begin{aligned} &\sum_{i=1}^{N} \left[d_i^{sn} ln\left(\Phi\left(z_i'\frac{\beta}{\sigma} - \frac{t^1}{\sigma}\right) - \Phi\left(z_i'\frac{\beta}{\sigma} - \frac{t^2}{\sigma}\right)\right) + d_i^{ss} ln\left(\Phi\left(z_i'\frac{\beta}{\sigma} - \frac{t^2}{\sigma}\right)\right) \right. \\ &\left. + d_i^{ns} ln\left(\Phi\left(z_i'\frac{\beta}{\sigma} - \frac{t^2}{\sigma}\right) - \Phi\left(z_i'\frac{\beta}{\sigma} - \frac{t^1}{\sigma}\right)\right) + d_i^{nn} ln\left(1 - \Phi\left(z_i'\frac{\beta}{\sigma} - \frac{t^2}{\sigma}\right)\right) \right] \end{aligned} \tag{6}$$

where d_i^{sn}, d_i^{ss}, d_i^{ns}, and d_i^{nn} are indicator variables that represent the values of survey responses (i.e., s = yes, n = no).

3.4. Empirical Analysis

To analyze the collected data, STATA 15 was used [35]. After performing the exploratory factor analysis (EFA) on consumer perceptions of environmental concerns, the author utilized EFA results (i.e., underlying dimensions of consumer perceptions) as one of the independent variables in the double-bounded dichotomous choice model for sustainable aquaculture [36–38]. An economic variable (i.e., household income), socio-demographic variables (e.g., age, family size, and gender), and seafood preference (frequency of consuming seafood) were also included in the estimation model.

Traditionally, economic variables (e.g., household income) are essential for estimating economic models, such as a demand model. Socio-economic variables became important for describing a demand function along with the economic variables [39]. The seafood preference variable is an extended version of socio-economic variables; the variable is a useful indicator for measuring the preference for aquaculture products [40]. In the current study, the author set the frequency of seafood consumption as a proxy variable to measure seafood preference.

After conducting the CVM analysis, the present research compared the mean WTP by the level of the NEP scale. The author used the mean of the composite NEP score, categorizing respondents into two groups: high NEP and low NEP. The mean WTP was compared for both groups to examine group differences by the NEP level (i.e., level of environmental concern).

4. Results

4.1. Descriptive Information

The sample profile shows that 50.4% of the respondents are female and 49.6% are male, with equal age group distribution (Table 4). Furthermore, 66.5% of the respondents are married, and 33.5% are single. In terms of education level, 64% of the respondents have a bachelor's or postgraduate degree. More than half of the respondents were between 20 and 49 years old at the time. Most annual household incomes fall between $54,654 and $76,363, accounting for 22.1% of the respondents.

Table 4. Sample demographics.

Variable	Categories	Frequency	Percentage
Gender	Male	496	49.6
	Female	504	50.4
Age	20–29 years	182	18.2
	30–39 years	198	19.8
	40–49 years	248	24.8
	50–59 years	232	23.2
	More than 60 years	140	14.0
Marital status	Married	665	66.5
	Single	335	33.5
Family size	1 person	108	10.8
	2 persons	198	19.8
	3 persons	257	25.7
	4 persons	351	35.1
	More than 5 persons	86	8.6
Employment status	Primary/Secondary occupation	54	5.4
	Self-employed	83	8.3
	Sales/Customer service	70	7.0
	Office job	349	34.9
	Business/management	75	7.5

Table 4. *Cont.*

Variable	Categories	Frequency	Percentage
	Professional/freelance	119	11.9
	Housewife	135	13.5
	Student	69	6.9
	Unemployed	46	4.6
Education	Equivalent to high school	187	18.7
	Two-year college degree	122	12.2
	Undergraduate students	57	5.7
	Bachelor degree graduate	536	53.6
	Equivalent to postgraduate	98	9.8
Annual household income *	Less than $21,818	104	10.4
	$21,927~32,727	146	14.6
	$32,836~43,636	176	17.6
	$43,745~54,545	174	17.4
	$54,654~76,363	221	22.1
	$76,472~98,181	105	10.5
	More than $98,290	74	7.4

* in USD.

4.2. Exploratory Factor Analysis Results

Exploratory factor analysis produced two-dimensional factors, such as nature and balance and human dominance (Table 5, Item). The eigenvalues for the factors were 2.374 and 1.699, respectively (Table 5, Eigenvalues). Items under nature and balance loaded highly on factor 1; human dominance items loaded on factor 2. The Cronbach's α for both factors exceeded 0.70, which is the minimum requirement for item reliability [41].

Table 5. Exploratory factor analysis results.

Item	Factor 1 Loadings	Factor 2 Loadings	Uniqueness	Cronbach's α	Eigen Values
Factor 1: Nature and balance					**2.374**
A3	**0.6434**	0.0878	0.5783		
A5	**0.6771**	0.0941	0.5326		
A7	**0.6443**	0.1226	0.5698	0.79	
A9	**0.5398**	−0.0198	0.7083		
A11	**0.5549**	0.1596	0.6666		
A15	**0.6462**	0.2343	0.5275		
Factor 2: Humandominance					**1.699**
A2	0.0270	**0.5803**	0.6626		
A10	0.2864	**0.6280**	0.5236	0.75	
A12	0.0944	**0.6591**	0.5567		
A14	0.1383	**0.6508**	0.5573		

Note: Items are stated in Table 2.

4.3. Estimation of Willingness-to-Pay for Sustainable Aquaculture Products

According to the double-bounded choice model estimation, household income is significant, whereas respondent attitude is partially significant. The demographic variables are insignificant, whereas seafood preference is statistically significant (Table 6, *p*-value).

The author estimated consumer WTP based on the CVM results. WTP for 1 kg of live red seabream (i.e., sustainable aquaculture products) is ₩48,951 (Korean won), which is equivalent to $44.5/kg (USD) (Table 7, coefficient). This amount is about $10 higher than a conventional aquaculture product (i.e., live red seabream). In the estimation, insignificant variables (human dominance and demographic variables) were excluded, whereas household income, nature and balance, and seafood preference were considered.

Independent samples T-test results show that the high NEP group has more WTP for sustainable aquaculture products—as much as ₩5901 or $5.36/kg (Table 8, Mean).

Table 6. Estimated parameters for the double-bounded choice model.

Variables	Coefficient	Std. Error	z	p-Value
Household income	13.08	3.58	3.66	0.000
Nature and balance	3968.51	1026.79	3.86	0.000
Human dominance	−153.49	678.40	−0.23	0.821
Age	1881.27	2152.10	0.87	0.382
Family size	−1677.80	1814.38	−0.92	0.355
Gender	−612.23	1546.33	−0.40	0.692
Seafood preference	1011.30	272.14	3.72	0.000
Constant	16,405.84	6590.88	2.49	0.013

Note: Log likelihood = –1140.0169, Wald chi-square (7) = 55.75, p-value > Wald chi-square = 0.0000. z = z-score.

Table 7. Willingness-to-pay for sustainable aquaculture products (red seabream/kg).

	Coefficient	Std. Error	z	p-Value
Willingness-to-pay	48951	4748	10.31	0.000

Note: The unit is Korean Won; $1 (USD) to ₩1100, ₩48,951 = $44.5 (USD).

Table 8. Mean comparison between high NEP group and low NEP group.

Group	Obs.	Mean	Std. Error	Std. Dev.
Low NEP group	438	45,633.96	255.83	5354.15
High NEP group	562	51,535.48	201.92	4786.89
Combined	1000	48,950.62	184.36	5830.05
Difference		–5901.52	321.43	
		t = –18.3598, d/f = 998, p-value = 0.0000		

Note: NEP, New Ecological Paradigm, Obs. = the number of observation, Mean = mean value of WTP.

5. Discussion

For this study, the NEP scale was used to measure consumer perception of the environment and its underlying dimensions were identified. EFA results indicated that consumer perception comprises two dimensions: nature and balance and human dominance, yielding two indicators as independent variables in the contingent valuation method estimation. A double-bounded CVM model enabled estimation of WTP for sustainable aquaculture products (e.g., live red seabream) farmed using a copper-alloy aquaculture net system. The CVM estimation results indicated that the demographic variables and the consumer perception variable of human dominance are insignificant, while the economic variable, the consumer perception variable of nature and balance, and seafood preference are significant. Moreover, the present research estimated the WTP for sustainable aquaculture products by comparing the mean WTP by NEP level groups.

In economic theory, income is one of the most important variables for determining product demand and consumption [42]. Our estimation results show that the coefficient of household income is positive: higher household incomes show higher WTP for sustainable aquaculture products. Solgaard and Yang [43] reported similar results too. Their model shows that household income positively affects the price premium for sustainable aquaculture products.

Consumer perception of the environment is a significant variable that affects WTP. Numerous studies have examined the effect of consumer perceptions on consumer behavior [43–48]. For example, Solgaard and Yang [43] found that pro-environment consumers had a 25% greater payout for sustainable aquaculture products and securing animal welfare; here, the demographic variable and household income were significant. However, Solgaard and Yang focused more on animal welfare than on consumer perception of the environment because they lacked reliable instruments to measure consumers' environmental concern. To overcome this limitation, the author introduced the NEP scale in the context of seafood marketing.

The author divided the survey respondents into high and low NEP groups to examine the mean difference of WTP between the two groups. The difference is statistically significant, showing a price premium that reaches ₩5901 (i.e., $5.36). This finding is consistent with previous research. For example, Kotchen and Reiling [21] used the NEP scale to measure respondents' perceptions, revealing that attitudes toward the environment could influence WTP for nonuse value of endangered species. Paul et al. [48] used the theory of planned behavior to analyze how consumers' environmental perceptions and attitudes affect their behavior. Instead of CVM, they used structural equation modeling to analytically investigate behavioral intent (rather than WTP). Their results indicate that environmental concerns affect attitudes toward pro-environment behavior, subjective norms, and perceived behavioral control. Such constructs eventually affect behavioral intentions. Overall, the perception of the environment is more likely to affect consumers' WTP. Our study provides empirical evidence for this mechanism.

Uniquely, the study findings considered seafood preference as a crucial variable affecting consumer WTP. Some research has attempted to include food-related variables in research models [43,49]. For example, Solgaard and Yang [43] found that consumers who understand the characteristics of seafood products were also willing to pay more money. Klöckner et al. [49] analyzed the effect of country of origin and echo-labeling on CVM, concluding that knowledge of food affects CVM. Such results are consistent with the present results. Notably, the food-related variable is meaningful—the current research found that those who consume seafood regularly and frequently are willing to pay more money.

6. Conclusions

The present research explored the consumer WTP using double-bounded choice modeling (CVM). The research findings provide significant implications for the aquaculture industry. Sustainable aquaculture is likely to be costlier than conventional aquaculture. Even though copper-alloy farming nets are eco-friendly, most fish farmers use nylon farming nets as they are less expensive. Sustainable aquaculture minimizes the environmental impact, improving environmental sustainability, as well as its values. However, the market does not yet fully reflect these values, exhibiting a typical example of a negative externality. To resolve this issue in the aquaculture industry, the government should either support aquaculture or create opportunities for the market to recognize and reflect environmental values, along with compensation for sustainable aquaculture producers. Compensation could include retailers' commitment toward favorably handling sustainable aquaculture products or a price premium in the market. The ASC certification is an excellent example of such a mechanism.

The author identified the price premium for sustainable aquaculture using the CVM method. Originally a measurement tool for values, it helped us determine which variables could affect values: income was identified as a significant variable. Note that the income level in South Korea has increased in the last three decades, leading up to gross national product per capita of $30,000, which is expected to continue increasing in the future along with consumer WTP.

Environmental perception is a crucial factor affecting the WTP for sustainable aquaculture products. The perception reportedly increases consumer-based environment activities and strengthens consumer awareness of the environment's importance [50]. For example, because of the spread of sustainable aquaculture certification systems (e.g., ASC, Friend of the Sea, Naturland, and GSSI), organizers are actively promoting marketing activities to increase consumer awareness of the environment. The response in the market has been positive: Hilton Worldwide, IKEA, and

Carrefour, for example, now serve ASC products [51], whereas at the Rio Olympics 2016, organizers served ASC products at the dining courts [52].

Seafood preference (i.e., frequency in consuming seafood) is an important variable for CVM in sustainable aquaculture. It can be measured by consumption frequency and amount. In South Korea, seafood consumption has been steadily increasing since 2009. According to FAO [53], seafood consumption per capita for all populations is around 20 kg, but consumption in South Korea is far above this amount. Annual per capita seafood consumption in South Korea has increased from 50.52 kg in 2009 to 59.86 kg in 2016 (See Appendix A). Thus, the Korean seafood market has more potential to generate price premiums for sustainable aquaculture products compared with other counties.

South Korea has the potential to transition to sustainable aquaculture through consumer participation. However, the focus of its current aquaculture policy is not on quality, but on production volume-oriented measures. The government must urgently shift to sustainable aquaculture because consumer expectations are now higher than expectations of government officials and fish farmers.

Finally, the current study is not free from limitations. The present research focused on red seabream, a cage-farmed species, as well as aquaculture cage net selection, which represent only one aspect of sustainable aquaculture practices. Although red seabream is a typical aquaculture species in South Korea and the copper-alloy aquaculture net is a promising technology for sustainable aquaculture, it is difficult to generalize our findings to the entire aquaculture industry based on an analysis of one species and technology. Therefore, future research should expand the scope of sustainable aquaculture research.

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Conflicts of Interest: The author declares no conflict of interest.

Appendix A

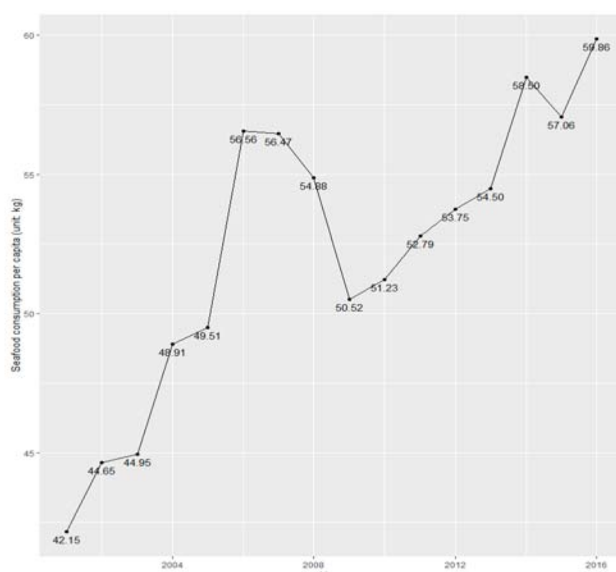

Figure A1. Seafood consumption per capita (unit: kg). Source: Adopted from Korea Rural Economy Institute [54]; 2016 Food Balance Sheet.

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Fishing Community Sustainability Planning: A Roadmap and Examples from the California Coast

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Abstract: Fishing communities are facing a variety of challenges including declines in participation, reduced access to fish resources, aging physical infrastructure, gentrification, competition from foreign imports, the "graying" or aging of their fleets, along with a host of environmental stressors. These factors can represent threats to the continued viability of individual fishing communities. Such communities are clearly in need of tools that will enable them to plan strategically and to be more proactive in charting a sustainable future. This manuscript provides a roadmap for how to engage fishing communities in a bottom-up strategic planning process termed "fishing community sustainability planning" by describing implementation efforts in four diverse California ports: Morro Bay, Monterey, Shelter Cove, and Eureka. The process draws from the literature on sustainability and community development to assess fishing community sustainability around four broad categories: economics and markets; social and community; physical infrastructure and critical services; environment and regulation. Process steps included developing a project team and community coalition, analyzing baseline data, conducting interviews with waterfront stakeholders, hosting public workshops, and drafting a Fishing Community Sustainability Plan (FCSP) that includes concrete recommendations for how a community's fishing industry and waterfront can be improved. Experiences from the four ports reveal that fishing community sustainability planning can be adapted to a variety of contexts and can contribute tangible benefits to communities. However, there are limitations to what community-scale planning can achieve, as many regulatory decisions that affect communities are enacted at the state or national level. Combining community-level planning with scaled-up fishing community sustainability planning efforts at the state and federal level could help overcome these limitations. FCSP planning is one tool fishing communities should consider as they seek to address threats and plan for their long-term viability.

Keywords: fishing community; sustainability; seafood; strategic planning; port; California

1. Introduction

Typically, conversations about seafood sustainability focus on the status of fish stocks and resources. However, a conversation about seafood sustainability might also consider the status of communities who rely on fish resources for a variety of economic, social, and cultural purposes. Food resources from the sea cannot be sustained if the communities and individuals who harvest the resources are not also maintained [1,2]. Research shows that fishing communities in the U.S. and globally are increasingly confronted with threats to their long-term sustainability. Challenges include rising operational costs, stagnant market prices, competition from foreign imports, shifts in consumer preferences, shifts in the labor market, aging physical infrastructure, gentrification, declines in participation, and reduced access to fish resources, along with environmental stressors that can affect fish resource health [3–9]. Many fishing communities are also experiencing a "graying of the fleet" where the average age of a commercial fisherman (The term fisherman is used throughout the paper as it is the preferred term among community members we spoke to. It is meant to denote individuals of any gender who participate in fishing.) is rising as there are fewer new, younger entrants into the industry [10–12]. The combination of these factors leads to concerns about the long-term viability of commercial fishing communities in the U.S. and beyond. Fishing communities are clearly in need of tools that can enable them to be proactive and to strategize for a more sustainable future.

Scholarship in the field of community development and sustainability consistently emphasizes the importance of community-based strategic planning and future-thinking as a means to guide communities toward a more sustainable path [13–16]. A key pillar in the maritime port sustainability management system presented by Kuznetov et al. [15] (p. 67) is "strategic planning for the future." In an assessment of 57 rural communities who participated in community development activities, Fey et al. [13] (p. 16) found that communities who "write a strategic plan to begin community economic development efforts" and who "articulate a long-term, unifying vision" are likely to perform "higher" in terms of achieving tangible development outcomes. This research also emphasizes the importance of conducting strategic planning with a bottom-up approach that is inclusive of a variety of community perspectives, rather than relying on input from a few elites [13,14]. Sustainability frameworks developed for seafood systems, ports, and fishing communities have also highlighted the importance of community organization, governance, or planning [2,15,17–19]. This research can be brought to bear on the experience of fishing communities to ask: What should strategic planning for fishing communities look like and what is the best method for engaging fishing community constituents in a bottom-up visioning process related to the future of their communities?

This paper describes the design and implementation of a process to engage fishing communities in strategic planning for the future called "fishing community sustainability planning". The paper draws from experiences implementing community-level planning efforts with four diverse California fishing communities: Morro Bay, Monterey, Shelter Cove, and Eureka. The paper will detail fishing community sustainability planning processes in four sections by presenting:

1. A review of the literature related to sustainability and fishing communities along with a simple, actionable framework that we utilized to assess and plan for fishing community sustainability. The framework draws from the relevant literature and is set in the context of U.S. fishery policy.
2. A description of the four case-study communities where fishing community sustainability planning was implemented and the planning methods that were utilized in each community.
3. A description of steps of and findings from an inclusive, bottom-up planning process that the authors used to engage the four fishing communities in strategic planning. The process culminated in the production of a Fishing Community Sustainability Plan (FCSP) for each community.
4. An overview of the outcomes and/or benefits that have been documented in the four communities who engaged in FCSP processes.

The goal of this paper is to introduce the concept of fishing community sustainability planning and to provide a roadmap for communities and planners who may be interested in engaging in similar efforts. The planning processes involved the collection of over 200 interviews with waterfront stakeholders, the hosting of 10 public workshops, and 20 presentations to local government entities across the four ports. This analysis will incorporate data from the interviews, meetings, and plans in the description of the process steps, findings, and outcomes.

2. Literature and Framework

2.1. U.S. Fisheries Policy Context

The 1996 reauthorization of the United States federal fisheries act, the Magnuson-Stevens Act (MSA), included a provision called National Standard 8 directing federal fisheries managers to "take into account the importance of fishery resources to fishing communities by utilizing economic and social data that are based upon the best scientific information available in order to: (1) Provide for the sustained participation of such communities; (2) To the extent practicable, minimize adverse economic impacts on such communities" (50 CFR § 600.345(b)(3)). While the policy only directed managers to consider community concerns, it did create the idea of a fishing community as an important unit of analysis. Additionally, by directing attention to the "sustained participation" of fishing communities, the standard directs researchers and managers to better understand the factors that underlie fishing community sustainability as well as to manage with an aim of maintaining or increasing that sustainability.

In United States fisheries, the Magnuson-Stevens Act (MSA) (16 U.S.C. § 1801 et seq.) sets the fishing community definition used by governments and many researchers. The MSA ties communities to place and defines a fishing community as "a community which is substantially dependent on or substantially engaged in the harvest or processing of fishery resources to meet social and economic needs, and includes fishing vessel owners, operators, and crew and United States fish processors that are based in such a community" (50 CFR § 600.345(b)(3)). The MSA definition is important because it makes a regulatory link between the management of fisheries and their connection with the communities that rely on them for their livelihoods [20].

The notion of a "community sustainability plan" (CSP) in relation to fishing emerged out of text from a different part of the MSA from the 2006 reauthorization of the law. The MSA states, "to be eligible to participate in a limited access privilege program to harvest fish, a fishing community shall ... develop and submit a *community sustainability plan* [emphasis added] to the Council and the Secretary that demonstrates how the plan will address the social development needs of coastal communities ... ". According to the law, fishing communities that wish to participate in limited access fisheries need to develop and present a CSP to the regional fishery management council. However, commercial and recreational fishing communities and civic leaders also began to view the CSP as an opportunity to develop a strategic planning document for the entire local fishing industry that could produce multiple benefits for the community. They added the term "fishing" to the document title to create fishing community sustainability plans (FCSPs). The ports of Morro Bay and Monterey undertook CSP projects to leverage the establishment and strengthening of their community quota funds as well as to remain eligible to participate in the West Coast Individual Transferable Quota (ITQ) Groundfish Trawl fishery (a limited access privilege program). Additional communities have engaged in FCSP processes for the strategic planning benefits without an expressed interest in entering a limited access fishery.

The MSA policy text does not explicitly define "sustainability" and does not provide any more details about what is to be included in CSPs, leaving fishing communities and planners with the latitude to make choices about how they want to approach the concept of sustainability and what they want to include in planning efforts. We, the authors of this manuscript, worked with fishing communities and consulted the literature to develop a framework and process to assess fishing community sustainability and produce a strategic plan that would be accessible to and actionable by waterfront stakeholders.

2.2. Fisheries, Fishing Communities, and Sustainability

Sustainability is notoriously difficult to define and the theory and thinking behind the concept has developed considerably over the past few decades [21,22]. Original conceptions emphasized the sustainability of environmental systems [23], but the concept has branched into myriad types of sustainability as it has been adopted by other disciplines [24]. One sustainability framework that is popular and applied to a wide range of situations is known as the Triple Bottom Line (TBL). Tracing back to the Bruntland Report [25], the TBL framework attempts to assess or manage for sustainability through social, economic, and environmental lenses [26–28]. Scholars have critiqued the TBL for its clear ties to a business setting and because the approach can seem vague or hollow in application [15,29]. However, the TBL has opened the door for a more holistic approach to the sustainability concept.

There have been several efforts to develop frameworks that specifically connect sustainability concepts to seafood systems, ports, and fishing communities. Micheli et al. [2] present a framework for assessing Seafood System Sustainability (SSS). Their approach incorporates 30 indicators across the three broad categories of governance, socioeconomic, and ecological. Anderson et al. [30] created a Fishing Performance Indicators (FPI) assessment tool grounded in the TBL approach to include community, economics, and ecology indicators. Kuznetsov et al. [15] developed and implemented a Port Sustainability Management System (PSMS) for smaller ports in the UK. They conceive port sustainability around nine “pillars” which are linked to a variety of topics including safety, assets, environment, stakeholders, and planning. While a fishing community is intricately connected to its port and that port’s sustainability, it encompasses a somewhat different set of components and needs from an entire port system. Adrianto et al. [19] attempt to develop a sustainability framework for fishing communities, using the example of Yoron Island, Japan. They stress the importance of developing “local accepted” (LA) sustainability indicators that conceptualize the community in a way that community members would understand. They outline four components of fishing community sustainability—ecology, economy, community, policy—and break these components into specific indicators.

The literature on community development, which draws predominantly from case studies of rural, natural-resource dependent communities, can also contribute to thinking about fishing community sustainability. The community capitals framework (CCF) separates a community’s assets into seven interdependent capitals: social, human, cultural, political, financial, built, and natural [31]. Scholars posit that a solid foundation in all capital areas can contribute to a “healthy ecosystem, vital economy, and social well-being” [13] (p 11). Empirical research suggests that strategic investment in some capital areas can lead to a rise in other capital areas, causing a community to “spiral up” to a more sustainable and economically viable state [16].

2.3. Fishing Community Sustainability Framework

We structured our strategic planning efforts around a sustainability framework that drew from the literature and applied those concepts to issues specific to fishing communities. Our fishing community sustainability framework included four broad categories: economics and markets; social and community; physical infrastructure and critical services; environment and regulation. Table 1 outlines each of the categories, describes what aspects of fishing communities they include, and shows how they are connected to other sustainability concepts and frameworks from the literature. Infrastructure is not a commonly-used dimension in sustainability frameworks like the TBL. But our work and other research efforts showed that infrastructure and critical services were essential to the basic functioning and sustainability of a port or fishing community [15,32]. We used this basic framework to assess baseline conditions of the fishing communities and to develop recommendations to improve community sustainability.

Table 1. Fishing community sustainability planning framework used in the planning processes for this paper and its connection to sustainability indicators or metrics from the literature.

Component	Definition in Community Context	Connection to Frameworks from Literature [1]
Economics and Markets	The nested financial systems related to fishing and the waterfront which range from the financial relationship between captain and crew on a fishing boat to the fish buyers and processors, local markets, regional markets, and global markets for fish products. Includes the diversity and number of seafood buyers and processers; the prices, landings, and total value of products being landed in a port a given year; the local, regional, and international markets for various marine resource products; product marketing strategies; the recreational/charter fishing tourism economy.	TBL: Economic CCF: Financial Capital PSMS: Business Planning and Management SSS: Socioeconomic FPI: Economics LA: Economy
Social and Community	The people who make up the social networks with a connection to fishing in a specific location. Includes the cultural context; the state of the workforce; social networks, relationships and trust; political organization.	TBL: Social CCF: Social Capital, Human Capital, Cultural Capital, Political Capital PSMS: Stakeholder Engagement, Proactive Partnerships, Effectiveness of Management Processes SSS: Socioeconomic, Governance FPI: Community LA: Community, Policy
Infrastructure and Critical Services	Includes the infrastructure and services necessary to support fishing activities such as docks, piers, marinas, moorings, fish processing plants, cranes, fuel stations, cold storage, ice facilities, ramps/launch facilities, haulout facilities, repair shops, gear shops, and gear storage areas. Also includes dredging of waterways, jetties and shoreline armoring which maintain shorelines and access to bodies of water, and transportation infrastructures such as roads, airports, and rail. Land use and zoning related to the waterfront and rents and wharfages are also part of this category.	TBL: N/A CCF: Built Capital PSMS: Asset Management and Maintenance, Safety Management SSS: N/A FPI: N/A LA: N/A
Environment and Regulation	Includes the marine resources to be harvested and the ecological conditions necessary to sustain them such as habitat, food webs, ocean conditions, water quality, and human impacts. Also includes the physical geography of the port and potential influences from ocean hazards and sea level rise. Includes factors that are very local to a fishing community as well as regional and global systems such as meta-ocean conditions, weather patterns, and global environmental change. The category also includes the regulatory framework linked to fishery and environmental conditions. The regulatory processes contribute to the protection of the marine environment as well as dictate a fishing community's level of access to marine resources for harvest.	TBL: Environment CCF: Natural Capital, Political Capital PSMS: Environmental Knowledge and Awareness, Environmental Management SSS: Ecological, Governance FPI: Ecology LA: Ecology, Policy

[1] TBL = triple bottom line [26]; CCF = community capitals framework [13]; PSMS = Port Sustainability Management System [15]; SSS = Seafood Systems Sustainability indicators [2]; FPI = Fisheries Performance Index [30]; LA = locally accepted fishing community indicators [19].

We believe that sustainability in all four of the categories is essential for the long-term viability of fishing communities and the strategic plans should seek to generate improvements, expansion, or investments in all the areas. We found that the different categories were connected to and reliant on one another in specific ways when it came to fishing communities. Figure 1 shows the conceptual model of fishing community sustainability that drove our planning efforts. The model shows environmental systems—and the regulatory frameworks that guide their protection—at the base because a functioning fishing community is reliant on a healthy and sustainable resource to harvest. Without resources and without access to those resources, a fishing community could not exist. Infrastructure is shown above the environment, as a fishing community is similarly dependent on infrastructure to function and obtain landings at the port. Without basic infrastructures such as working vessels, docks to store boats, dredged channels, boat launches, hoists, ice, and fuel, fishermen cannot catch fish. The community or social system is depicted on top the environmental and infrastructure components—this includes attributes of the human community itself, social relationships, level of participation, the state of the workforce, and cultural ties. Finally, economics and markets are shown above the community as this is where fishermen, processors, and others take the resources they have harvested and exchange them outward to markets, local and global, to bring economic revenue to the community.

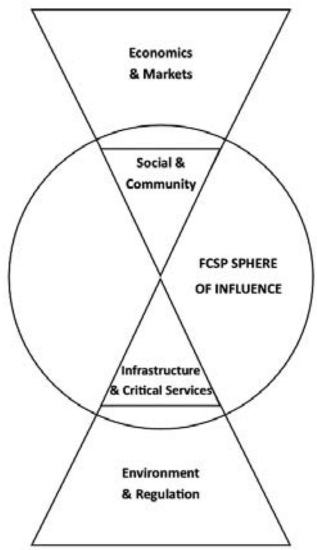

Figure 1. A conceptual diagram of fishing community sustainability that informed FCSP processes in this manuscript.

We also discovered that strategic planning on the community scale might not be capable of influencing all of the factors relevant to a fishing community as some factors occur at scales outside the sphere of the individual community influence. The circle in Figure 1 depicts the FCSP sphere of influence. Community-based FCSP efforts can influence most aspects of infrastructure and the community's social system which are more local in origin and operation. However, some aspects of environmental regulatory processes and seafood markets occur at scales and scopes well beyond the community, so FCSP planning may not be able to fully address all concerns in those areas. The greater the distance between the fishing community and a decision-maker in either geographic distance or political echelon, the less leverage a single FCSP is likely to have on the outcome.

3. Materials and Methods

3.1. Case Study Communities

This paper draws from planning processes conducted with fishing communities connected to four ports in California (Figure 2). These ports vary substantially in terms of their size, landings, and available infrastructure (Table 2).

Figure 2. Location of study ports in California that engaged in fishing community sustainability planning efforts (by Lisa Wise Consulting, Inc.).

Table 2. Comparison of the ports where fishing community sustainability planning projects were conducted.

Port	# Comm. Vessels 2014 [1]	Landings (lbs) 2014 [1]	EVV 2014 [1]	Top Species	# CPFV 2014 [1]	Mariculture Operations 2018
Morro Bay	157	6,751,323	$7,887,699	Coastal pelagic species (CPS), Spot prawn, salmon, groundfish	3	Oyster; 2 businesses
Monterey	124	67,673,187	$20,137,268	CPS, squid, groundfish, Dungeness crab	6	Abalone; 1 business
Shelter Cove	24	84,580	$332,938	Dungeness crab, salmon, nearshore finfish	3	N/A
Eureka	163	14,785,049	$13,017,412	Dungeness crab, groundfish, shrimp, salmon	7	Oyster and clam; 6 businesses

[1] Number of vessels, landings, ex-vessel value (EVV), and number of Commercial Passenger Fishing Vessel (CPFV) operators; data from California Department of Fish and Wildlife, California Fisheries Data Explorer.

Shelter Cove is the smallest, and likely most vulnerable of the four ports. Shelter Cove is rural and isolated geographically and politically. Shelter Cove is unincorporated so development in the area is overseen by the county, whose seat is in Eureka about two hours away. The community has a

Resort Improvement District that is primarily responsible for managing utilities and fire protection as well as overseeing a few recreational areas in the community. In addition, the Humboldt Bay Harbor, Recreation and Conservation District (HBHRCD), also based in Eureka, has responsibility for overseeing aspects of port infrastructure including the jetty and boat launch site. None of the three government entities with authority in the Shelter Cove area have asserted primary responsibility for the waterfront and as a result, some aspects of waterfront management have been neglected over time. At the beginning of the FCSP process, Shelter Cove did not have an active fishing association. The community lacks the basic infrastructure found in most ports; there are no docks or marinas and boats must be launched via an unreliable tractor service. There is no ice, cold storage, nor processing facilities and only one buyer who comes to the community. Most fishermen must truck their catch out to markets hours away on their own. In 2014, 24 commercial vessels fished out of Shelter Cove, but in recent history that number has dropped to as low as seven. Shelter Cove engaged in FCSP planning as an opportunity to plan strategically about how they could maintain their status as a fishing community and keep commercial and recreational fishing activities viable.

Morro Bay is a small to medium-sized port by California standards. The port contains a mix of smaller-scale, community-based vessels, and one or two active trawlers. Tourism is also an economic driver in the Morro Bay waterfront. The port of Morro Bay falls entirely within the City of Morro Bay and port and waterfront activities are overseen by the City's Harbor Department. At the time of FCSP implementation, Morro Bay had an active fishing association—the Morro Bay Commercial Fishermen's Organization—which was formed in 1974 and has had fluctuating membership between 80–120. The organization played a strong role throughout the FCSP process. Due to environmental, regulatory, and market challenges, the industry took a significant downturn and between 1990 and 2007; the total value of landings at the port dropped from approximately $8.5 million in 1990 to $1.9 million in 2007. However, in 2012 earnings at the dock in Morro Bay rebounded to over $6.3 million. In 2014, when the FCSP was completed and accepted by the Morro Bay City Council, earnings were over $7.8 million. The community engaged in FCSP planning as a necessary step for their community quota fund and "to assess current baseline conditions and plan strategically for a stable and vibrant fishing industry and waterfront infrastructure" [33] (p. v).

Eureka is one of the largest ports in California, consistently within the top 10 in the state for landings. The fishing community encompasses fishing and mariculture activities throughout Humboldt Bay. Key port infrastructure and development is managed by a patchwork of local government entities including the City of Eureka, Humboldt County, and the HBHRCD. The fishing fleet has an active fishing association—the Humboldt Fishermen's Marketing Association (HFMA)—which was founded in 1955, is managed by a board of directors and has had a fluctuating membership of 65 to 150 fishermen. Members of HFMA have been politically engaged at the local, state, and federal level on behalf of the area's fishing interests. In 1992 there were 445 active fishing vessels in Eureka and that number dropped to 143 by 2006, but between 2006–2014, there has been a stabilization and even slight increase in the number of vessels [34]. Eureka has important amenities such as four fish buyers and/or processors, marinas and docks, and two boat haulout facilities. However, the port faces challenges including lack of cold storage, unreliable dredging, encroachment on the waterfront by other uses, graying of the fleet, and overreliance on a single fishery (Dungeness crab). Humboldt Bay, where Eureka is located, has an active mariculture industry that produces an estimated 70% of the state's oysters. Eureka engaged in FCSP activities to help promote broader community understanding of the benefits from the working-waterfront as well as to identify key needs and to help secure funding and political support to address those needs.

Monterey has a similar number of active vessels to Eureka and Morro Bay, but the value of the landings tends to be higher, with over $20 million in earnings in 2014. Monterey supports a diverse array of fisheries including nearshore fisheries such as crab and rockfish, trawl fisheries, squid, and coastal pelagic species (CPS) such as sardine and anchovy. Most of the fishing community infrastructure and activities are within the City of Monterey. Port management is overseen by a harbormaster who is appointed by the Monterey City Council. At the time of implementation, Monterey did not (and still does not) have a fishing association specific to the port; however, fishermen from Monterey were involved in several regional, state, or West Coast fishing organizations. Additionally, the harbormaster has been politically engaged on behalf of fishing community interests. Currently, the harbormaster holds a seat on the Pacific Fishery Management Council, which is the body that makes decisions about federal fisheries off the West Coast. The city of Monterey is a mid-size, relatively affluent city and tourism has become an important driver of activity in the waterfront. This has led to the ghettoization of commercial fishing, now limited to Municipal Wharf II, and concerns about additional encroachment of tourism and other activities into space designated for working-waterfront activities. The port has the potential for continued and improved relationships with marine conservation entities including the Monterey Bay Aquarium and Monterey Bay National Marine Sanctuary [35] and Moss Landing Marine Lab.

3.2. Planning Methods

We conducted extensive community-planning activities in each of the four study ports. A detailed description of the planning process and data analysis approaches can be found in Section 4.1 which outlines the Roadmap or process used to guide our planning efforts. Riggs and Pontarelli [36] also provide an overview of the Morro Bay and Monterey processes. Overall, we conducted semi-structured interviews with 211 stakeholders connected to the study communities; 10 planning meetings or workshops; and 20 presentations to local government entities such as City Councils, Harbor Commissions and County Boards of Supervisors (Table 3). We also conducted regular site visits in each study community and conducted a review of existing documents and secondary data related to each port. Interview data will be cited with an abbreviation of the port where conducted and the year.

Table 3. Timing and FCSP planning activities conducted in each of the study ports.

Port	Year (s)	Interviews	Public Workshops	Advisory Committee Meetings	Local Government Presentations
Morro Bay	2013–2014	24	2	0	6
Monterey	2012–2013	80	2	0	6
Eureka	2017–2018	61	1	2	6
Shelter Cove	2017–2018	46	1	2	6
TOTAL		211	6	4	20 [1]

[1] Total number of local government presentations lower than the sum of individual port presentations as during some single presentations multiple FCSP processes were discussed.

4. Results and Discussion

4.1. Roadmap

The goal of the FCSP process is to develop bottom-up, constituent driven plans focused on creating sustainable futures for fishing communities. This FCSP process has been refined through implementation experiences in four different communities. The planning process will differ from community to community depending on their unique needs and context. However, we have found that the broad set of steps below represent an effective approach for engaging fishing communities in long-range strategic planning. Below is an outline of the seven broad steps that we took in our FCSP planning approach including a description of the implementation processes and findings from the four featured FCSPs, as well as recommendations for future planners and communities who may wish to conduct similar processes. Table 4 provides an overview of the process steps as well as the primary actors involved in each step.

Table 4. Process steps for FCSP implementation and primary actors involved in each step.

#	Step	Primary Actors [1]
1	Develop Coalition and Project Team	LGOV, PROJ, FISHCOM
2	Assess Baseline Conditions	PROJ
3	Host Meetings and Public Workshops	PROJ, FISHCOM, PUBL
4	Semi-structured Interviews and Site Visits	PROJ, FISHCOM
5	Data Analysis and Recommendations	PROJ, FISHCOM
6	Draft Plan, Review, and Final Plan	PROJ, FISHCOM, PUBL, LGOV
7	Outreach and Implementation	FISHCOM, LGOV, PROJ

[1] LGOV = local government officials and staff, elected leaders; PROJ = Project team responsible for carrying out planning activities (often planning consulting firm or members of academia); FISHCOM = members of the fishing community; PUBL = members of the general public.

4.1.1. Develop a Coalition and Project Team

The first step of our FCSP efforts was to ensure that members of the fishing community—with fishermen at the core—were invested in the process. Our FCSP processes have taken different approaches to project organization. In three of the ports, the process was truly grassroots as members of the fishing community approached local government officials, planning consulting firms, or academics directly to ask them to help develop FCSPs. In Shelter Cove, a smaller, more rural port, the fishing community was unaware of the FCSP process, so project team leaders approached community members about engaging in such an effort. Only when the community agreed did the project team consider the pursuit of funding. Fishermen and community members can also play a role in helping to define their fishing community and to determine key participants. Three of the ports included mariculture operations, and fishermen decided to include those interests in the FCSP planning process as they felt that fisheries and mariculture were stronger combined, and viewed as a concerted industry could make a greater appeal for priority investments and partnerships.

Once the interest and involvement of the fishing community were established, our project team worked to develop a coalition of support for the FCSP project. We found it was important to involve local civic leaders and elected officials as they ultimately approve the final FCSP and represent crucial partnerships for implementation of final recommendations. In the FCSP processes the authors engaged city, county, and port/harbor government officials during the early stages of project development and regularly presented project updates and gathered feedback at public meetings. Future planners may want to consider involving city councilmembers, county supervisors, congressional representatives, state legislators, locally-based environmental NGOs, fishing associations, regulatory agency staff, businesses leaders (Chamber of Commerce), local educational institutions and others.

After engaging a broader coalition, we developed a core project team that was responsible for overseeing the planning process. On the Morro Bay and Monterey FCSPs, the City of Morro Bay applied for and received the grant to fund both FCSP processes. Once the City was awarded the grant, they posted a public Request for Proposals (RFP). Through a public process, the city selected Lisa Wise Consulting, Inc. (LWC) (with co-author Pontarelli as the lead), an economics and urban planning firm with extensive fishing community and waterfront experience, to lead the FCSP process. LWC then worked closely with city and harbor staff to develop FCSPs for Morro Bay and Monterey. In Shelter Cove and Eureka, a university professor (co-author Richmond) was the principal investigator on the project and she worked in collaboration with planning consultants from LWC to manage the planning process and develop final plans. In the academic model, graduate students played a large role in collecting and analyzing data.

The structure of the project team and coalition may vary with context. For example, because the ports of Morro Bay and Monterey are completely within their respective city boundaries, it made sense to have the Cities play a leading role in overseeing and implementing FCSP processes. Since the fishing communities of Shelter Cove and Eureka are both managed by a patchwork of different local government entities, with no one entity having sole authority, it made more sense to have the planning effort sit outside of any one specific government entity and instead be overseen by researchers from a local academic institution. FCSP planning provides a great opportunity for members of local government, academia, industry and the private consulting world to work together and learn from one another.

Developing FCSPs is a labor-intensive process and communities or local governments will need to obtain funding to support the development of the documents. The National Fish and Wildlife Federation Fisheries Innovation Fund and the National Oceanic and Atmospheric Administration (NOAA) Saltonstall-Kennedy Grant program funded these FCSP processes. These are potential funding sources for future planners in the U.S. Local government entities can also choose to finance the project with their own budgets and there may be additional local, state, or federal economic development and/or coastal protection funds available for this type of work.

4.1.2. Assess Baseline Conditions Through Analysis of Existing Data

The second step of the process was to gather together existing data, plans, and reports in order to collate and synthesize archival information so it could be leveraged to inform the analysis and reporting. We retrieved and analyzed government documents, academic reports, county assessor data, census data and landings/logbook data to provide a clear assessment of the baseline conditions of the fishing community. We presented summaries of the fisheries data and statistics at public workshops and planning meetings so that members of the community could use the data to discuss port strengths, weaknesses, and areas for investment. We aimed to develop clear and accessible materials that summarized the existing data; materials included PowerPoint presentations, posters, and the text of the plans themselves. Not all members of the fishing communities had access to computers or the internet, so a key goal of this step was to provide fishing communities with access to existing data and information that could be useful to them. We recommend that future planners keep in mind that obtaining fisheries data at the port or community scale may require forming memoranda of understanding or non-disclosure agreements with government entities, a potentially time-consuming process. As such, it may be important to begin this step as early as possible in the planning process.

4.1.3. Host Meetings and Public Workshops to Facilitate Community Engagement

To facilitate a community-driven process, our project teams met with representatives of the community regularly for input and guidance and to inform the community of the progress of the project. We found it helpful to schedule regular meetings with a small number of fishing community representatives who were committed to the process, worked well with others, and represented the range of interests on the working waterfront. In the ports of Shelter Cove and Eureka, we took an additional step to formalize community involvement by establishing an Advisory Committee in each port. The Shelter Cove committee consisted of 12 members and Eureka, 16. The Advisory Committees met formally two times during the process: (1) to introduce the project, present background data, help with introductions to key participants, and to begin brainstorming and (2) to present preliminary findings and discuss possible plan recommendations. We worked closely with fishing community representatives to schedule meetings at appropriate times and times of years so that meetings did not conflict with important fishing windows or other relevant events. Additionally, in Shelter Cove and Eureka, advisory committee members were provided with a small stipend to compensate them for their time commitment to the project.

In addition to meetings with a small group of community representatives, we hosted at least one public planning meeting or workshop in each community, where any interested community members could provide their input related to a vision for the future of the port. The public workshops also provided an avenue to educate the broader community about the value of the working waterfront. The format for public workshops varied. The ports of Morro Bay and Monterey each hosted two public workshops related to their FCSP processes. The workshops began with a formal presentation and ended with an opportunity for the public to provide input. The Shelter Cove and Eureka workshops were conducted in a charrette-style where members of the public could mingle and examine posters displaying port data as well as interact at different stations and write their ideas for community improvement on butcher paper, post-it notes, or dictate to a project representative (Figure 3). In addition, when attendees entered the venue, they were given 50 "play" dollars and asked to distribute the money among their highest priority investments. After the event, the project team tallied the amount of money that went to each hypothetical investment. The results from the Eureka exercise can be seen in (Figure 4).

Figure 3. Shelter Cove public meeting workshop hosted in 2017. In the background, participants debate how to invest their "Shelter Cove Bucks" in potential port projects and place the play money in the labeled manila envelopes of their choosing. In the foreground, participants sit at a station with a facilitator where they brainstorm ideas on butcher paper (photo: Robert Dumouchel).

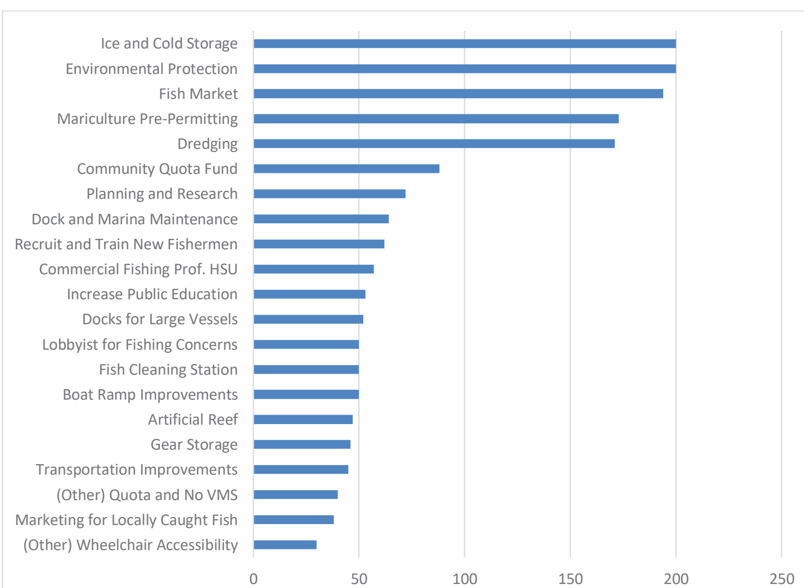

Figure 4. Results from activity at the Eureka public workshop where participants were given 50 "play" dollars and asked to put the money into the projects in which they would invest.

4.1.4. Semi-Structured Interviews and Site Visits

The primary method for ensuring that the FCSP reflects the community's view of the port was the conduct of semi-structured interviews with waterfront stakeholders. For this process, we conducted interviews with open-ended questions that enabled respondents to drive the interview process in a conversational style. The survey instrument consisted of four key questions, In your opinion: (1) What is going well in the port? (2) What are the challenges that the port is facing? (3) What have you seen done in other ports that worked well? (4) If you had $5 million to make improvements to the local fishing industry how would you invest it? Interviews ranged from 20–90 minutes. We often had two team members at each interview, one to ask questions and the other to take notes. The goal of the interviews was to gain an insider's perspective on the strengths and weaknesses of the port and potential avenues for improvement and investment. This data formed the basis for research and the foundation of recommendations. We targeted individuals to make sure all user groups in the waterfront were represented. The goal of the interviews was to achieve saturation, rather than a statistically representative sample. The combination of targeted interviews with public workshops and advisory committees allowed us to hear from a variety of individuals associated with each fishing community rather than just hearing from the most vocal or engaged.

Throughout the project period, our team members conducted regular site visits to key locations on the waterfront; they also sought to attend any public meetings or discussion related to the waterfront that occurred in the study communities during the planning period. This method, often called participant-observation, helped the project team to build relationships and trust with waterfront users as well as to observe how the fishing community functioned—and its potential strengths and weaknesses—in real-time.

4.1.5. Data Analysis and Recommendations

After the public workshops, semi-structured interviews, site visits, and secondary data collection, we began analyzing the data to help inform the development of an FCSP with a list of recommendations to improve the sustainability of the fishing community. We used qualitative analysis techniques to analyze the interview, public meeting, and participant observation data [37]. First, we sought to develop frequency graphs related to responses to interview questions 1, 2, and 4 about community strengths, weaknesses, and priority investments. Members of the project team reviewed all of the interview responses for each question for a given community. The team then developed a master list of the different responses to each of the three questions and sought to group the responses together into themes or bundles. The goal was to develop a list that encompassed all possible responses. The team then developed a Google Forms© instrument that contained a list of the possible responses for each of the three main interview questions. We then filled out the Google Form© for each interview conducted—selecting the various strengths, weaknesses, and priority investments that were brought up in any given interview event. After all the interviews had been analyzed, Google Forms© provided a summary output of the frequency with which different responses were given to a particular question. These frequency graphs (see example in Figure 5), helped the project team identify the top concerns and priorities among waterfront stakeholders. In addition to developing numerical graphs, the project team sought to organize qualitative responses. For this analysis, we coded the interview data based on the four fishing community sustainability categories (which were also chapter headings in the final FCSPs) and we used the coded data to develop a list of representative interview quotes for each of the sustainability categories to integrate into the final FCSP document as well as other published materials. Analysis of secondary data and existing reports supplemented the assessment of strengths and areas of concern in the port.

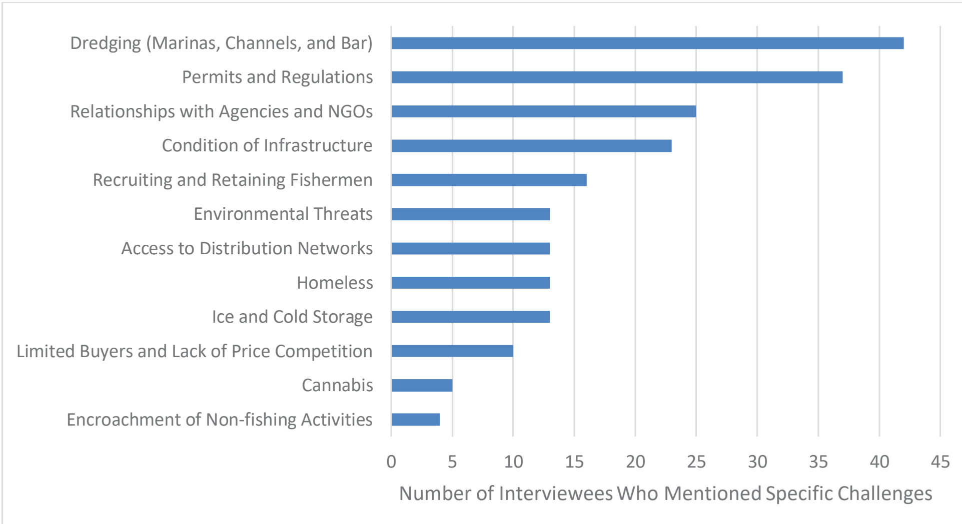

Figure 5. Graph depicting the number of individuals that cited a particular challenge during semi-structured interviews with waterfront stakeholders from Eureka. Based on interviews with 64 individuals.

Figure 5 shows the results of the interview analysis for the community of Eureka, highlighting the top investment priorities provided in response to interview question four. The results show how the immediate context of the port can influence the community response. Dredging was the most common priority for investment. This prioritization is likely related to the fact that during the FCSP project, dredging had been delayed and was reaching a crisis level where several boats were stranded at the marina during low tide. In the year following the interviews, dredging had been completed. While it remained a priority, it may not have dominated interview responses in a different year. Future planners should be aware of the pull of the current context on the planning process and try to ensure that short term emergencies do not overwhelm the long-term vision for the community.

A comparison of Figure 5 with Figure 4, which shows the top recommendations from the public meeting in Eureka, highlights the importance of including both public workshops and stakeholder interviews in the planning process. In stakeholder interviews in Eureka, the top priorities for investment related to items within the fishing community such as infrastructure and permit/regulation requirements. In the Eureka public workshop, attendees introduced new priorities that related to their vantage point as community members who interact with but are not necessarily a part of the working-waterfront community. The top recommendation from the public workshop was environmental protection and the third priority was a fish market as members of the public were concerned that it was difficult for them to purchase locally-caught fish. Another concern from the public workshop related to wheelchair accessibility to ensure that all members of the community are able to access waterfront areas.

After analyzing and organizing data, we developed a draft or a "long list" of plan alternatives. These "alternatives" were actions that the community could take to help reduce vulnerabilities and improve the long-term resilience of their port. The alternatives were selected based on their ability to address the weaknesses or challenges listed by waterfront stakeholders as well as to improve or maintain key port strengths. Alternative ideas came directly from community members in interviews and public meetings. Alternatives were also developed through a consideration of activities in other ports that have been successful in addressing key concerns. We selected alternatives to ensure that all four aspects of sustainability highlighted in the FCSP framework were addressed in each plan.

After developing a long list of alternatives, we met with a group of fishing community representatives to review and prioritize alternatives. Community members reflected on missing items and discussed how they want to organize or prioritize the recommendations in the plan. The port of Morro Bay chose a streamlined list of 10 recommendations. They felt a more targeted list would be easier to achieve as policy-makers and champions in the community would not be overwhelmed and could better focus energy and resources. Monterey decided that all of the 34 alternatives should be included as recommendations in their final plan. Shelter Cove chose 13 key recommendations and included seven other items that deserved further attention. Eureka chose 12 recommendations, but rather than listing them in priority order, they organized their recommendations based on the four categories of sustainability.

Final recommendations for the four plans are included in Appendix A. The 63 recommendations across the four ports are color-coded based on the primary sustainability category, with the acknowledgement that many recommendations could address multiple categories. Appendix A reveals that all the communities included recommendations that addressed all four sustainability categories. Recommendations aimed at Infrastructure and Critical Services were the most common, accounting for 48% of the total. Social and Community recommendations accounted for 22% and Economics and Markets 20% of the total. Environment and Regulation recommendations were the lowest accounting for just 10%.

The high number of infrastructure recommendations as well as infrastructure needs expressed in these planning efforts (Figures 4 and 5; Appendix A) demonstrate that infrastructure development and maintenance is an important priority for fishing communities in California. In efforts throughout the four ports, we consistently noted concerns about declining and missing infrastructure. Infrastructure investment remains a high priority for these communities, as many basic aspects of a fishing community cannot function without working infrastructure. Infrastructure and Social were the most common types of recommendations, and this may also be linked to the fact that, as Figure 1 shows, these are the areas that FCSP planning at the community scale is best poised to address. Environmental recommendations were the least common. This could be linked to the Central and Northern California context, where fisheries are some of the most regulated in the world and where many fisheries once in decline have been listed as recovered [38,39]. Representatives of the fishing community may have felt that environmental sustainability was fairly well-addressed through existing policies and that the long-term sustainability of their fishing community required a greater focus on infrastructure and socioeconomic elements.

Appendix A shows that the recommendations differed from community to community. Each fishing community was able to make the FCSP framework work for their unique context and needs. While the recommendations differed across the ports, there were some commonalities. All four communities included recommendations related to political engagement and organization, increased access to or involvement in fisheries, protection of waterfront uses from encroachment, investment in key pieces of port infrastructure, and efforts to improve market options for seafood. Each of the ports contained recommendations that were linked to short-term emergencies or concerns—for Eureka it was dredging, for Shelter Cove it was developing a sustainable launch system, and for Morro Bay and Monterey it was related to developing community quota funds which were much in discussion during the planning processes. However, the ports also included recommendations that were focused on the long-term sustainability of the port beyond present-day emergencies, with, for example, recommendations related to sea level rise adaptation and the recruitment and retention of new participants in the fishing industry. Overall, the final recommendations show that within the process communities were able to balance their short-term and long-term needs and to develop strategic plans that focused on both.

4.1.6. Draft Plan, Review, and Final Plan

After all of the data had been gathered and analyzed, the project team wrote a draft FCSP. The goals of the FCSPs were two-fold: (1) to educate the greater community about the fishing industry and the working-waterfront and highlight its value and (2) to deliver a clear set of recommendations which the fishing industry with local government officials and others can implement. We sought to develop plans that were written in clear, accessible language with attractive visuals [33–35,40]. The plans began with an Introduction and then chapters that described the current setting or baseline conditions of the fishing community. The structure tended to adhere to the sustainability framework with chapters about the Social, Economic, Environmental, and Infrastructure conditions. However, communities could make decisions to add additional sections of interest to them. For example, Monterey decided to include an additional section, Rents and Wharfages, as it was an area of critical and universal concern. After describing the setting, the FCSPs included a chapter with the Recommendations. This chapter outlined the community's top priorities and included specific information about the next steps and potential funding sources to implement those recommendations. The plans ended with a chapter about potential Funding Sources or avenues through which recommendations could be implemented. We found that providing clear information about how to fund recommended actions can be crucial to ensuring their implementation. The draft plans were then circulated for review by members of the fishing community and local government officials. The feedback from the review process was incorporated into revisions for a final FCSP.

4.1.7. Outreach and Implementation

Once the final FCSPs were developed, project team leaders and members of the fishing community conducted extensive outreach to make sure that the findings reached a wide audience. Outreach activities included presenting findings at local government meetings (City, County, Port/Harbor) as well as at state and federal fisheries-related meetings. In Monterey and Morro Bay, local government entities such as city councils voted to formally "accept" the contents of the plan, which helped to formalize their commitment to the plan contents [33,35]. We found that outreach was aided by the development of a project website and a social media presence that included updates and the final content of the plans (see e.g., www.humboldtfishplan.com). Project leaders also worked with local media outlets to provide the public with information related to the FCSPs.

On all four FCSP experiences from this manuscript it was the intent of the fishing community to make positive change and to achieve implementation; in other words, to "build something" (MOR, 2013). No one wanted a plan that would sit on the shelf. So, once the plans were complete, planners handed off the FCSP to the fishing community from which they could take direction to advocate for the priorities and to make them come to fruition. The Morro Bay and Monterey processes showed that the implementation of plan priorities takes time and requires persistence and leadership from the fishing community. Some plan recommendations, such as the formation of fishing associations or developing better political engagement, fishing communities were able to implement on their own and in a short time. Other recommendations such as those related to infrastructure required partnerships with local government entities, funding, and a longer path to completion. We found that fishing community engagement and persistence to implement the plan after it had been completed was a crucial part of the FCSP planning process.

4.2. Outcomes

Interviews conducted throughout the project, follow-up conversations with planning participants, and an assessment of community activities and progress provide a window into some of the outcomes or benefits that the study communities experienced as a result of participating in FCSP processes.

4.2.1. Implementation of Beneficial Actions

Over time, we have observed that FCSP processes have played a key role in helping fishing communities to implement actions that lead to direct benefits to their overall social, economic, and environmental sustainability. The Monterey and Morro Bay FCSPs were completed in 2013 and 2014 respectively and those communities have already made progress towards implementing several of their FCSP recommendations (Appendix A). In the Morro Bay FCSP, the number one priority recommendation was a boatyard and haulout facility. The plan was approved by the City Council in 2014, the City funded a Demand Analysis in 2015, conducted a preliminary site plan in 2016 and released a Design Build RFP in 2017. Morro Bay has also taken significant steps to address recommendation five (Political engagement and support of community-based fishermen), by increasing their engagement in political processes and working with the Pacific Fishery Management Council and others to help improve the pathway for smaller community-based vessels to utilize the groundfish quota held by their community quota fund. In 2017, the City of Morro Bay completed a Sea Level Rise Vulnerability Assessment and Policy Framework, which was the ninth recommendation from their FCSP.

Key recommendations in the Monterey FCSPs included the formation of a community quota fund and a fishermen's organization or association. In 2014, the Monterey Bay Fisheries Trust (MBFT) was formed with a mission to "advance the social, economic and environmental sustainability of Monterey Bay fisheries" [41]. The MBFT was in the process of formation as the FCSP was developed. The FCSP fulfilled the federal requirement under MSA which allowed the organization to purchase quota and the FCSP helped the fishing community convince the City Council to purchase $225,000 in quota for the MBFT to manage. In the years since, the MBFT has acquired additional permits and fish resources, leading to a clear economic benefit for the fishing community. In addition to purchasing quota, the MBFT has played many of the political engagement roles typically associated with a fishing association. They have been active and effective players in policy discussions at the federal (another FCSP recommendation), state, and local level. The Monterey FCSP also included recommendations related to zoning and protection of fishing and working-waterfront industries from encroachment by other uses. In 2016, the City of Monterey issued a Waterfront Master Plan that incorporated several of the FCSP recommendations. The Master Plan specifically references the FCSP and states, "The recommendations [in the FCSP] are consistent with the Waterfront Master Plan Goals, Programs, and Projects regarding preservation of Monterey's fishing heritage" (p 10). The Master Plan includes goals to ensure that use and development in working-waterfront areas "encourages and supports the preservation of the Monterey fishing industry" (p. 65). The Monterey FCSP also included a recommendation for developing local markets for Monterey-based seafood and community supported fisheries (CSF). Since the plan's implementation, a small-scale CSF called Monterey Local Catch expanded their operation and in 2015 rebranded as Real Good Fish, and that company has since expanded to offer CSF subscriptions in several California ports.

The Eureka and Shelter Cove FCSPs were issued very recently, so there has been less time for implementation of recommendations. However, the community of Shelter Cove has already taken steps to implement their top two priorities: form a fishing association and establish a sustainable launch service. In October of 2018, the community began meeting regularly to discuss forming an association and with the assistance of a legal consultant they have developed an organizational structure and filed paperwork to form a non-profit organization called Shelter Cove Fishing Preservation, Inc. (SCFP). In 2018, the Humboldt Bay Harbor District announced that they were no longer going to be responsible for the tractor launch service at Shelter Cove as the Harbor District is based in Eureka two hours away, and it has been difficult to manage the distant operation of services. The newly formed SCFP is in negotiations with the Harbor District to take over the launch operations. This will enable the operations to be maintained and supported by a community-oriented group that may be better positioned to ensure the service's continued operation and reliability.

4.2.2. Building Social and Political Capacity

All of the ports in this study had undergone a period of decline. Between 1992–2006, the number of commercial vessels operating out of each of the ports had dropped by more than half. In 2006, Shelter Cove had seven active vessels, but community members described a fleet of over 100 vessels operating out of the port in the 1970s and 1980s. These declines have all shown a leveling off and after 2006 the ports all seem to be maintaining a steady or increasing number of participants, suggesting a clear path forward for the industry. But the declines have had serious effects on the morale and capacity of fishing communities. Once strong fishing associations had languished or lapsed, instances of conflict within the fishing community or with government entities were common, and local governments, perhaps guided by the false belief that fishing was a 'dying industry', were less focused on working-waterfront needs. One fisherman from Shelter Cove described the fishing industry as being "out of sight out of mind" (SC, 2017), and another said, "This place is pretty hard to get anyone to do anything" (SC, 2017). Pessimism was common in the ports, with statements such as, "everything [in the port] is on a downhill slide" (EUR, 2017) and "not much is working well in Shelter Cove" (SC, 2017). A Eureka stakeholder summed up this atmosphere of conflict with the following statement, "if you want a friend on the waterfront, get a dog" (EUR, 2017). Fishermen also described how the onslaught of regulatory changes over the past decades has caused the fishing industry to shift to a defensive mode, where they are always looking to prevent or limit damage from potential decisions as opposed to think about their future: "We are not looking forward—we want no net loss—so it is hard to look forward" (EUR, 2017).

FCSP processes appear to have played a strong role in helping fishing communities develop their social and political capacity and in bringing local government attention back to the needs of the fishing industry. The FCSPs from these processes were high-quality documents on par with Specific Plans and other local government plans and reports. Experiences in Morro Bay and Monterey suggest that the industry and harbor management's access to these plans helped to elevate the importance of the fishing community and industry in the eyes of local governments, making the working-waterfront an increased area of focus for planning and investment initiatives. Since the FCSP was complete, the City of Morro Bay has worked closely with the fishing community to implement recommendations, such as developing a boatyard and haulout facility. The City of Monterey has similarly taken their port's FCSP into consideration and specifically referenced the FCSP in future planning documents like the Waterfront Master Plan. The FCSP process also provided an opportunity for fishermen, agency staff, local government officials, and other stakeholders to engage with one another outside of controversial issues or area of conflict. Previously, these stakeholders most frequently engaged with one another during emergency or crisis situations, such as the planned implementation of restrictive fisheries policies or conversations about controversial waterfront developments. The FCSP process provided an opportunity for waterfront stakeholders to work together and to understand that they all have a common goal: the long-term sustainability of their port's fishing community.

Perhaps the most dramatic transformation occurred in the community of Shelter Cove—a community that demonstrated pessimism and frayed social relationships at the beginning of the project. Sparked by, and in parallel with, the FCSP process, they worked to develop a fishing association. In the span of three short months of intensive meetings, they had submitted their paperwork to the IRS to form the organization. When a member of the fishing community was asked if things have changed in Shelter Cove over the two years of FCSP planning, he stated that the community has already improved their outreach to and working relationship with local government entities (SC, 2018). At a December 2018 meeting of the HBHRCD, one commissioner stated that he was impressed by the way the Shelter Cove community has "showed real capacity" in their interactions, and how he "can't thank the fishermen enough for stepping up to the plate" (HD, 2018) to work with the HBHRCD on the launch service. When asked to describe how social relationships in Shelter Cove have changed in the past two years, which coincided with FCSP planning, a community member stated that he's seen a "tearing down of walls in the community" where "there's slow but a greater social enlightenment how everybody who wants to be involved in the maritime [area] is in the same boat together." He said the fishing community has started to "rally together in a way that hasn't happened in the past" (SC, 2018).

5. Conclusions

We found that FCSP processes can be a great tool to engage fishing communities in strategic planning for the future of their ports and that implementing FCSP processes can produce tangible and intangible benefits for fishing communities. The planning process can also help to improve community relationships and trust by engaging fishermen, local government, agency staff, and other stakeholders on a task with a common vision: improving the long-term viability of the fishing community. In the four processes we conducted, we found that nearly every interest group and stakeholder was supportive of the FCSP process and plan recommendations. For some fishermen, the experience was revelatory—seeing that local government and agency staff are not always against them and were instead interested in a vibrant future for their industry.

As with any planning or economic plan, FCSPs have their limitations. All of the FCSPs to date have been developed at the community or port scale. This scale of analysis can be helpful for addressing challenges linked to social networks and infrastructure or land use. However, we found that many of the structural challenges facing fishing communities have their roots in decisions that are made at the state and national level. All communities described challenges with access to resources for their small-scale operators and with recruiting and maintaining new and younger participants into the industry. The high cost of permits, limited access to fish resources, and lack of financing or low-interest loans were cited as challenges. These challenges are linked to federal and state policy and allocation decisions. Additionally, funding for infrastructure projects often comes from federal or state sources.

FCSP planning on the community scale alone may not be enough to make the substantive changes necessary to ensure the long-term viability of fishing communities. A next step would involve a scaling-up of the FCSP process—to conduct strategic planning for fishing communities at the regional, state, or national scale. This process could identify consistencies in needs and contributions among ports and give the industry a greater voice. Fisheries management agencies such as the California Fish and Game Commission or the U.S. Regional Fishery Management Councils could sponsor these planning processes. Planners could consider findings from a variety of community-level investigations to develop recommendations that could be implemented at the state and federal level to help ensure the viability of fishing communities. Scholars of natural resource management highlight the importance of incorporating nested scales into effective management regimes [42,43]. This nesting of scales may also be important for strategic planning for natural resource-dependent communities. A combination of community-level and regional planning efforts could contribute to the long-term sustainability of fishing communities as well as the seafood industry overall which is reliant on healthy and thriving fishing communities to harvest the resources.

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Appendix A

Table A1. Recommendations contained in the FCSPs for each of the four study ports, in the order they were listed in the plan. Recommendations are color-coded based on the primary sustainability category they seek to address. White = Infrastructure and Critical Services; Light Gray = Economics and Markets; Medium Gray = Social and Community; Black = Environment and Regulation.

#	Morro Bay	Eureka	Shelter Cove	Monterey Part I	Monterey Part II
1	Boatyard/ Haulout Facility	Protected Marine-Dependent Uses	Fishing Association and Political Engagement	Congestion and Improving Truck Access	Support Dialogue to Re-establish Monterey Bay Halibut Trawl Fishery
2	Fuel: Maintain Service and Reduce Costs	Cold Storage and Ice Facility	Reliable, Sustainable Launch System	Improve Safety Features on Wharf II	Establish Zoning for Fishing and Related Uses "By Right"
3	Refrigerated Storage and Deep Freeze	Dredging	Fish Cleaning Station Improvements	Identify and Evaluate Underutilized Sites	Establish a Special District for Working-Waterfront
4	Promotion and Marketing of Working-Waterfront	Mariculture Pre-Permitting and Permit Streamlining	Processing, Cold Storage, and Ice Facilities	Consider Uses for the Monterey Fish Company Warehouse	Greater Flexibility for Sub-tenant and Sub-leases On Waterfront
5	Community Participation, CQF	Gear Storage and Security	Greater Control Over Marina Property	Uses for the North Apron Area	Maintenance and Repairs
6	Increase Berths and Slips for Commercial Fleet	Dock and Marina Maintenance	Traffic, Circulation, and Parking Improvements	Encourage Retail Seafood Facilities: Wharf II	Make Business Planning a Waterfront Tenant Obligation
7	Feasibility Assessment for New Processing Facility	Markets Analysis and Development and Promotion	Maintenance of Boat Ramp	Establish and Independent Source(s) for Ice	Update the FCSP on three- or five-year Intervals
8	Improve Vehicle Access	Access to Commercial Fish Resources and CQF	Market Evaluation and Attract Seafood Buyers	Reduce Fuel Expenses for Fishermen	Develop Alliances with Tourism and the Business Community
9	Managing Sea Level Rise	Leadership and Political Engagement	Road Condition and Maintenance	Facilitate Establishment of A Commercial Fishing Oriented Chandlery	Develop Alliances with Agriculture Industry
10	Implement FCSP and Update	Recruit and Retain New Fishermen	Recruit and Retain New Fishermen	Allow Gear Storage and Mending	Engage in Collaborative Research
11		Habitat Restoration and Protection	Access to Commercial Fish Stocks/CQF	Offloading Hoist	Seafood Watch Program Involvement and Evolution
12		Collaborative Marine Research	Habitat Restoration and Protection	Continue to Support Alliance of Communities for Sustainable Fisheries	Improve Connections with Monterey Bay Sanctuary
13			Promotion of Tourism and Recreational Fishing	Commercial Fisherman's Organization	Employ Web-Based Tools and Social Media For Promotion
14				Pacific Fishery Management Council Participation	Establish a Fishing or Seafood Festival
15				Support the Formation of a CQF	Post Banners and Interpretive Signage
16				Reduce the Burden of Observer Costs	Develop CSF/ Local Markets
17				Support the Refinancing of the Federal Trawl Buy-back Loan	Bring Back the Juvenile Salmon Release Program

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Serving Local Fish in School Meals: The Nutritional Importance of Consuming Oily Fish

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Abstract: The European Food and Nutrition Action Plan 2015–2020 encourages Member States to promote local affordable and healthy dietary initiatives to support a sustainable food system, particularly in schools and public institutions where advertising on eating behaviour and food preferences is needed. In Italy, the promotion of healthy and sustainable diets, including the consumption of oily fish, is at an early stage. Based on the success of a unique Italian educational campaign in school lunch programmes, the aim of the present study was to compare the nutritional composition of locally caught anchovy and of imported frozen fillets of farmed Vietnamese pangasius, to observe the potential implications of this dietary substitution. Anchovy showed a significantly higher fatty acid and protein content than pangasius, and contained five times more lipids, mainly n-3 and n-6 polyunsaturated fatty acids. As previous studies confirmed, a diet providing large amounts of these fats is therefore recommended especially during childhood. The present findings highlight the high nutritional value and healthiness of serving locally caught fish in school meals, which plays a strong role in teaching good dietary habits for a lifetime. Further initiatives are needed to encourage responsible fish consumption during early life to promote a sustainable food system.

Keywords: school lunch programme; Italy; healthy nutrition; oily fish; sustainability

1. Introduction

Fish and seafood are major sources of important nutrients, such as essential fatty acids, proteins, vitamins, and micro-and macroelements [1]. In particular, they are high in polyunsaturated fatty acids (PUFA), mainly eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA), which provide documented health benefits, for instance by helping to reduce the risk of obesity, cardiovascular disease, age-related decline in multiple cognitive domains [2–4] and to enhance fetal development [5,6]. Oily fish, such as anchovy, sardine, mackerel and tuna-like have been linked to many of these health benefits [7,8]. Scientists together with global health advisory organisations recommend to the general adult population the consumption of at least one portion of oil-rich fish per week [9]. However, while the supply of fish is increasing in most countries, Europeans apparently only consume half of the recommended amount [10]. According to the European Food and Nutrition Action Plan 2015–2020 [11], Member States should promote local affordable and healthy dietary initiatives to support a sustainable food system, particularly in those settings such as schools and public institutions where advertising on eating behaviour and food preferences is needed [12,13]. Teaching good dietary habits early in life would help healthy ageing and maximize smart food choices for a lifetime. Furthermore, eating locally, especially in school meal programmes would encourage fish consumption during childhood and would strengthen local communities and economies.

Although the promotion of sustainable fish diets in schools across Europe exists, it is still limited to a few countries (e.g., UK and Portugal [14]; France [15]). In Italy, this is a recent development [16]. For instance, since 2013, *Pappa Fish: Eat Well, Grow Healthy!* a preliminary food educational campaign mainly financed by the European Maritime and Fisheries Fund (EMFF) and partly financed by local municipalities in the Marche region located in the central-east part of Italy, on the Adriatic coast, has been launched with the aim to introduce local oily fish and seafood into regional school canteens [16,17]. This was a unique initiative in Italy that connected a large number of stakeholders (i.e., public schools across local governments, administrators, school cafeteria workers, nutrition technologists, parents, teacher committees, school directors and the whole fishing industry) to educate new generations to a sustainable consumption of fish with high nutritional value. Between 2015 and 2017, the initiative involved 282 schools (approximately 30,000 children) based in 42 municipalities of the Marche region and a total of 90 tons of local seafood products used to prepare about 49,500 daily meals [16,17]. Meals were prepared by chefs and canteen committees with local fresh oily fish and seafood from the Adriatic Sea and were seasonally included in primary and secondary school canteen menus in Marche region. As part of the educational campaign, children were involved in over 800 practical workshops divided into more than 200 activities. Children were also trained and guided with storytelling and creative games to get to know the benefits and the high nutritional value of local fish and sea products coming from the Adriatic Sea. In this contest, it is important to understand clearly the nutritional implications of replacing imported frozen fish with local and seasonal fish. The replacement of low-cost imported fish products with locally caught species will certainly benefit local economies, promoting and supporting an affordable and sustainable food system, but whether this economic advantage would also translate into an improvement in the nutritional profile of the product supplied remains uncertain. From a nutritional quality perspective, does the consumption of local fish products constitute a dietary improvement?

The purpose of this study is to compare the nutritional composition of two representatives of both local and imported products present on the Italian market, in this case: local anchovy and imported frozen fillets of farmed Vietnamese pangasius. These two species are normally found in the meals served in school canteens [17,18]. Among the 15 local marine species considered in the *Pappa Fish* educational campaign see [16,17], the European anchovy (*Engraulis encrasicolus*) was chosen for chemical analysis as it is the major oily fish and one of the most important target species in the Italian commercial fisheries [19,20]. The Vietnamese pangasius (*Pangasius hypophthalmus*), instead, was considered as one of the most popular imported fish consumed in the European Union (EU), competing on the market with other white fish species like tilapia, hake, cod, haddock, Nile perch and Alaska pollock [21]. The European Union (EU) represents the largest pangasius importer, accounting for about the 22% of exported Vietnamese frozen pangasius fillets [22]. In this contest, we also discuss the importance of eating local healthy sustainable diets during childhood.

2. Materials and Methods

Fatty acid and protein content, ammonia concentration, and pH value were determined in three groups of fish samples:

- 24 fresh European anchovies (*E. encrasicolus*) caught by and obtained from professional fishermen in the Adriatic Sea (FHA);
- 24 frozen European anchovies (*E. encrasicolus*) caught by and obtained from professional fishermen in the Adriatic Sea (FRA);
- 8 frozen fillets of farmed Vietnamese pangasius purchased from a supermarket (FRP).

FHA and FRA (the latter thawed at room temperature, 25 °C) were gutted, headed, filleted and homogenised separately in a blender for about 60 s at 13,000 rpm and used to prepare 8 samples of muscle tissue, each weighing about 30 g (corresponding to 3 specimens). In the case of FRP fillets, the glaze liquid released by thawing was accurately removed and the drained fillets were homogenised in a blender for about 60 s at 13,000 rpm. Eight samples of muscle tissue, each weighing about 100 g (corresponding to one FRP fillet) were prepared for the analyses. A total number of 24 samples (8 per group) were analysed.

The fat content was determined according to the Soxhlet extraction method [23,24] and the ISTISAN Report 1996/34 [25,26]. Samples were weighed and placed into a cellulose extraction cartridge; the Soxhlet apparatus, containing the cartridge, was introduced into a distillation flask containing 150 mL of n-hexane and a few anti-bumping granules. Samples were extracted for 220 min (30–40 cycles/h), then the solvent was removed using a vacuum rotary evaporator. Overall, the extraction procedure took approximately 4 h. Fatty acids were then separated by gas chromatography according to ECC Regulations [27] using an Agilent/HP 6890 GC gas chromatograph according to ECC Regulations (Reg. ECC 2568/1991 11/07/1991 GU ECC L248; Reg. ECC 1429/1992 GU ECC L150). Proteins were determined using the copper catalyst Kjeldahl method [27] and the ISTISAN Report 1996/34 [25,26]. The procedure involves sample digestion with concentrated sulphuric acid using copper (II) sulphate as a catalyst, to convert organic nitrogen to ammonia, alkalisation, distillation of the liberated ammonia into an excess of boric acid solution, and titration with hydrochloric acid to determine the ammonia bound by the boric acid. The nitrogen content of the sample is calculated based on the amount of ammonia produced. Ammonia was determined by [24] pH was measured in samples homogenised with one part of deionised water according to [28,29]. All analyses were performed at the laboratory of Gruppo Bucciarelli srl (Ascoli Piceno, Italy). R software was used for the statistical analyses. Saturated Fatty Acids (SFA), Monounsaturated Fatty Acids (MUFA), PUFA, and ammonia concentrations, protein content, and pH values were visualised in a heat map using hierarchical clustering analysis and subjected to the Kruskal-Wallis test. The level of significance was set at $p < 0.05$. If significance was met, a post hoc Nemenyi test adjusted to χ^2 statistics was performed for pairwise multiple comparisons of mean rank sums.

3. Results

The results of the chemical analyses of FHA, FRA and FRP are reported as mean ± the standard deviation (see Table 1). The lipid content ranged from 0.709 g 100 g^{-1} in FRP to 3.849 g 100 g^{-1} in FHA and was highest in FHA and FRA; the difference was significant ($p < 0.05$). The protein values were significantly higher ($p < 0.05$) in FHA and FRA compared with FRP. The ammonia concentration was highest in FHA (194.6 mg kg^{-1}; $p < 005$) and lowest in FRP (42.00 mg kg^{-1}; $p < 0.05$). The pH value ranged from 6.4 to 8.0 (Table 1) and was highest in FRP (up to 8.008).

Table 1. Proximate composition of fresh *E. encrasicolus* (FHA), frozen *E. encrasicolus* thawed at room temperature, 25 °C (FRA) and frozen farmed Vietnamese pangasius (FRP) fillets. Values are reported as mean ± standard deviation.

	FRP	FRA	FHA
Lipids *	0.709 ± 0.022	3.783 ± 0.133	3.849 ± 0.117
Protein *	15.18 ± 0.725	19.56 ± 0.675	19.72 ± 0.675
Ammonia **	42.00 ± 4.140	194.6 ± 7.089	163.3 ± 10.44
pH	8.008 ± 0.043	6.516 ± 0.013	6.483 ± 0.019

* Lipid and protein values are expressed as g 100 g^{-1}; ** Ammonia values are expressed as mg kg^{-1}.

The fatty acids composition of the three sample groups is reported in Figure 1 and Table 2. Their total SFA, MUFA, and PUFA content varied significantly ($p < 0.05$; Table 3). Although similar fatty acids patterns (PUFA > SFA > MUFA) were found in all three sample groups, values in FRP fillets were 10 times lower ($p < 0.05$). Palmitic acid (C16:0) was the most abundant SFA in anchovy samples, accounting for more than 50% of total SFA, whereas stearic acid (C18:0) was the predominant SFA in FRP fillets; the concentrations of pentadecylic (C15:0), arachidic (C20:0), and heneicosylic (C21:0) acids were low (<0.01 g 100 g^{-1}) in all sample groups. As regards MUFA, palmitoleic (C16:1) and oleic (C18:1n9c) acids were the most abundant in all fillet groups, whereas gadoleic (C20:1) and erucic (C22:1n9t) acids showed the lowest concentrations. With regard to PUFA, n-3 FA accounted for more than 90% of the total PUFA content in all three groups. DHA (C22:6n3) and EPA (C20:5n3) were the predominant fatty acids in all groups, DHA accounting for more than 50% and more than 31% of total PUFA, respectively. n-6 fatty acids accounted for more than 50% of PUFA in FHA and FRA fillets and for less than 10% in FRP samples.

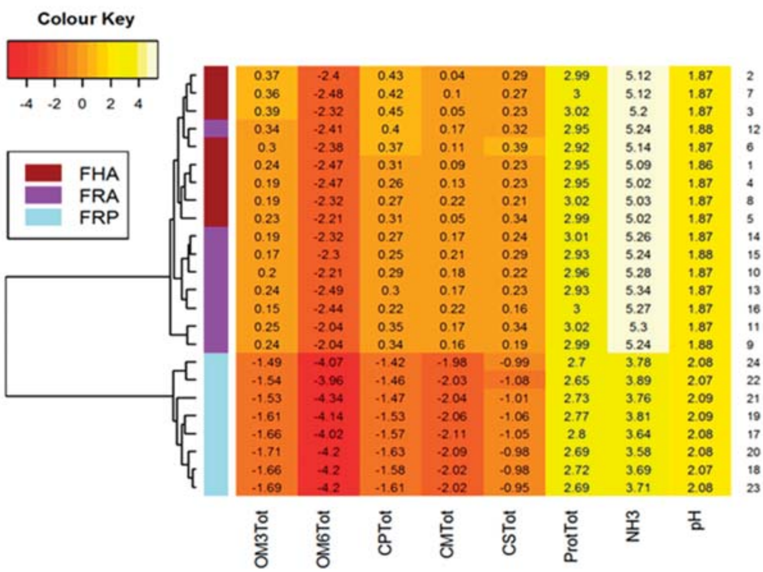

Figure 1. Heat map showing the differences in polyunsaturated fatty acids (PUFA), Monounsaturated Fatty Acids (MUFA), Saturated Fatty Acids (SFA) and protein content, ammonia concentrations and pH values among *E. encrasicolus* (FHA), *E. encrasicolus* thawed at room temperature, 25 °C (FRA), and farmed Vietnamese pangasius (FRP) fillets. Values are expressed in logarithmic scale. The colour gradient, from white to red, reflects increasing nutrient concentrations.OM3Tot = n-3 fatty acids content; OM6Tot = n-6 fatty acids content; CPTot =Total PUFA content; CMTot =Total MUFA content; CSTot = Total SFA content; ProtTot = Total protein content; NH3 = Ammonia concentration; pH = pH values.

Table 2. Fatty acid profile (g 100 g^{-1}) of FHA, FRA and FRP fillets. Values are reported as mean ± standard deviation. C 12:0 = Lauric acid; C 14:0 = Myristic acid; C 15:0 = Pentadecylic acid; C 16:0 = Palmitic acid; C 18:0 = Stearic acid; C 20:0 = Arachidic acid; C 21:0 = Heneicosylic acid; C 16:1 = Palmitoleic acid; C 18:1n9c = Oleic acid; C 20:1 = Gadoleic acid; C 22:1n9t = Erucic acid; C 18:2n6c = Linoleic acid; C 18:2n6t = Linolelaidic acid; C 18:3n3 = α-Linolenic acid; C 18:3n6 = γ—Linolenic acid; C 20:2 = Eicosadienoic acid; C 20:3n3 = Eicosatrienoic acid; C 20:3n6 = Homo-γ—Linolenic acid; C 20:5n3 = Dpan3 acid; C 22:2 = Docosadienoic acid; C 22:6n3 = Docosahexaenoic acid; Total n-6 = Total omega-6 fatty acids; Total n-3 = Total omega-3 fatty acids; n-3/n-6 = Ratio of omega-6 to omega-3 fatty acids.

Fatty Acids	FRP	FRA	FHA
Saturated, SFA			
C 12:0	0.0225 ± 0.00338	0.0157 ± 0.00341	0.01512 ± 0.00331
C 14:0	0.0668 ± 0.00356	0.2900 ± 0.03591	0.2975 ± 0.03732
C 15:0	<0.01	<0.01	<0.01
C 16:0	0.0742 ± 0.00471	0.7437 ± 0.04533	0.7525 ± 0.03955
C 18:0	0.2000 ± 0.01851	0.2350 ± 0.02927	0.2543 ± 0.03852
C 20:0	<0.01	<0.01	<0.01
C 21:0	<0.01	<0.01	<0.01
Total SFA	0.3636 ± 0.01631	1.2845 ± 0.08412	1.3188 ± 0.08598
Monounsaturated, MUFA			
C 16:1	0.0427 ± 0.00500	0.4250 ± 0.02563	0.3375 ± 0.04773
C 18:1n9c	0.0476 ± 0.00366	0.6637 ± 0.03814	0.6587 ± 0.03136
C 20:1	0.0196 ± 0.00226	N.R. < 0.1	N.R. < 0.1
C 22:1n9t	0.0195 ± 0.00325	0.1087 ± 0.01959	0.1087 ± 0.01807
Total MUFA	0.1295 ± 0.00537	1.1975 ± 0.02492	1.1050 ± 0.06866
Polyunsaturated, PUFA			
C 18:2n6c	0.0160 ± 0.00192	0.1035 ± 0.01837	0.0930 ± 0.00888
C 18:2n6t	N.R. < 0.1	N.R. < 0.1	N.R. < 0.1
C 18:3n3	0.0175 ± 0.00218	0.0137 ± 0.00168	0.0122 ± 0.00225
C 18:3n6	N.R. < 0.1	N.R. < 0.1	N.R. < 0.1
C 20:2	N.R. < 0.1	N.R. < 0.1	N.R. < 0.1
C 20:3n3	N.R. < 0.1	N.R. < 0.1	N.R. < 0.1
C 20:3n6	N.R. < 0.1	N.R. < 0.1	N.R. < 0.1
C 20:5n3	0.0672 ± 0.00523	0.4387 ± 0.03090	0.4512 ± 0.03870
C 22:2	N.R. < 0.1	N.R. < 0.1	N.R. < 0.1
C 22:6n3	0.1212 ± 0.01642	0.8012 ± 0.07754	0.8687 ± 0.08007
Total n-6	0.0160 ± 0.00192	0.1035 ± 0.01837	0.0930 ± 0.00888
Total n-3	0.2002 ± 0.01622	1.2513 ± 0.07581	1.3322 ± 0.10863
Total PUFA	0.2162 ± 0.01673	1.3548 ± 0.07986	1.4252 ± 0.10777
n-3/n-6 1	12.661 ± 1.79714	12.402 ± 2.20971	14.444 ± 1.82757

Table 3. P value of each pairwise comparisons of the mean concentrations of Monounsaturated Fatty Acids (MUFA), polyunsaturated fatty acids (PUFA), Total n-6, Total n-3, SFA, NH_3, pH and protein among the three samples groups (FHA, FRA and FRP). The colour gradient, from red to white, corresponds to increasing *p* values.

	FHA	FRA
MUFA		
FRA	0.23648	-
FRP	0.039	0.00012
PUFA		
FRA	0.63393	-
FRP	0.00055	0.01418
Total n-6		
FRA	0.75809	-
FRP	0.01014	0.00081
Total n-3		
FRA	0.67652	-
FRP	0.00064	0.01278
SFA		
FRA	0.8521	-
FRP	0.0012	0.0079
NH3		
FRA	0.077	-
FRP	0.077	0.000035
pH		
FRA	0.16	-
FRP	0.000072	0.05
Protein		
FRA	0.9393	-
FRP	0.0017	0.0056

4. Discussion

School lunch programmes are important for children's health, for their education and for their future wellbeing. By introducing culinary traditions in schools and school canteens, children should set the pattern for healthy habits in adult life. According to previous investigations, the traditional low consumption at early age of saturated fatty acids and the higher intake of complex carbohydrates (e.g., legumes and cereals) decreased in the Southern European countries including Italy [30]. Mediterranean countries are passing through a 'nutritional transition' in which problems of undernutrition coexist with overweight, obesity and diet-related chronic diseases [31]. The erosion of the Mediterranean diet heritage, by the loss of its adherence among Mediterranean populations, is alarming, as it has undesirable impacts not only on health but also on social, cultural, economic and environmental trends in the Mediterranean region [30]. In this contest, initiatives like *Pappa Fish* can contribute to increase the effectiveness of Mediterranean diet in Italy, promoting it as an educational model for nutrition and health promotion in public schools.

In the present study, local caught anchovy and frozen fillets of farmed Vietnamese pangasius were subjected to proximal composition analysis. The results demonstrated that anchovy fillets are characterised by higher nutrient concentrations than Vietnamese pangasius; in particular, their lipid content is five times higher than that of pangasius fillets. According to science-based nutrition standards, the anchovy lipid content is equivalent to that of low-fat meat (2–4%), whereas the content determined in pangasius fillets is similar to that found in lean meat (<2%) [32]. Total SFA, MUFA, and PUFA concentrations varied significantly between the two species. Similar FA profiles have been described in sardine, salmon, and herring [33,34]. Moreover, data analysis showed that the total n-3 and n-6 PUFA were 6–10 times higher in fresh and frozen anchovy, making them a valuable nutritional resource. Notably, fish and seafood are the only major dietary source of n-3 PUFA [1], which help prevent cardiovascular disease, age-related decline in multiple cognitive domains [2–4] and enhance fetal development [5,6].

Anchovy also had a higher protein content, as reported in an earlier study [33]. The lower protein content determined in Vietnamese pangasius has previously been described in fillets sold on different European markets (e.g., Italy [34]; Poland [35]; Germany [36]). According to [37] and similar studies [32,34–36], fish with high amounts of protein must contain greater than 15%. Furthermore, processing often involves the addition of large amounts of polyphosphates, which may increase water-binding capacity, thus reducing protein content [32,36].

The pH value—together with the concentration of ammonia and other substances—is a reliable indicator of freshness/spoilage [32,38]. The almost neutral pH found in anchovy fillets indicated that they have a good nutritional value. In contrast, the pH measured in the pangasius fillets, combined with their lower protein content, and reflected loss of freshness. These data agree with studies documenting that pH gradually increases during enzymatic protein degradation [36]. The ammonia concentration, which reflects the degradation of nitrogenous compounds, was higher in anchovy indicating that fresh fish should be consumed within 2–3 days.

The analyses performed in this study documented that locally caught anchovy had a higher nutritional value. PUFA accounted for a large proportion of total lipids. n-3 and n-6 PUFA, which help prevent several diseases, especially cardiovascular conditions [2,3,39], accounted for 35–40% of total lipids. As previous studies confirmed [7–9], a diet providing large amounts of these fats is therefore recommended especially during childhood [12,13]. Even though pangasius showed a good n-3/n-6 ratio, it has a considerably lower content in healthy fats [40].

The present study focused on the nutritional importance of a single local and important commercial species—the European anchovy—introduced in the Italian school lunch programme *Pappa Fish*. Further analysis, including more oily fish species, can be conducted to enhance the relevance of consuming local fish products. Eating small schooling species like anchovies can also reduce the carbon footprint because their fishing does not require farming or care of livestock like pangasius demands. To date, there is no study establishing the typical carbon footprint (CF) of frozen pangasius fillets imported to Europe. However, in [41] the assessment of carbon footprints of seafood consumed in Australia revealed that Vietnamese pangasius had the highest CF compared to other imported fish species at 9 kg CO_2e kg^{-1}, a higher footprint than hake (5.3 kg CO_2e kg^{-1}), and frozen salmon and flathead (both around 3 kg CO_2e kg^{-1}). The 98% of its CF was linked to the production process, with only 2% attributable to the transport phase. The farm stage in Vietnam was identified as the major source of carbon emissions for imported frozen seafood. Farmed fish in fact require the availability of feed, of variable nature and origin, that take energy to grow or catch, and then more energy in the processing stages. It is also suggested in [41] that in some cases, imported products can have lower CF than domestic products, but that production and transportation mode are important since they often generate more impact than distance travelled. On the other hand, wild caught seafood has often a lower CF than other animal proteins, but the generated impact varies greatly with the fishery involved. The most efficient fisheries are those targeting small schooling pelagic species like anchovies (*Engraulidae*), mackerel (*Scombridae*) and sardines (*Cupleidae*), while crustaceans' fisheries resulted among the least efficient form of animal protein production [42]. Unfortunately, small pelagic fisheries are often overlooked as a food option and instead used as an intermediate product in aquaculture and livestock production [42]. A comprehensive ecological footprint assessment of seafood consumed in Europe is clearly needed. Thus, the replacement of imported Vietnamese pangasius with local caught anchovy can be consider a step forward towards the enhance of a sustainable food system.

This study offers relevant information in view of the introduction of healthy and local fish and seafood in school meals in Italy. Consuming fish with high n-3 and n-6 polyunsaturated fatty acids content is crucial, since these fats can only come from the diet and oily fish, such anchovies, are one of the best sources. Anchovies caught in the Adriatic Sea are a traditional dietary staple of coastal communities [43] and they are perceived as highly healthy local products with a good nutritional profile, but difficult to cook [44]. As a result, many consumers prefer to buy less expensive products that are also easier to prepare (e.g., farmed fish fillets [45]). Awareness campaigns aimed at regular and occasional Italian consumers have recently been organized to promote the knowledge and image of local fishery products, highlighting underutilized local species as potential drivers of regional and national economic development [16,17,46,47]. However, none have explicitly recommended increasing their consumption for the health benefits they confer, underlining expressly their nutritional properties. Therefore, more information on the intrinsic quality attributes of local fish products and on their economic importance in EU is required.

5. Conclusions

The present study highlights the nutritional implications of replacing low-cost imported fish products with locally caught species. The results of the chemical analyses documented the high nutritional value of local anchovy fillets in terms of PUFA content and protein profile. Serving local fish products in school meals, which have excellent nutritional properties, play a strong role in in teaching good dietary habits for a lifetime. Further initiatives should be enhanced to encourage responsible fish consumption during early life and to support a sustainable food system.

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