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Climate change risks and adaptation options across Australian seafood supply chains - A preliminary assessment

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Abstract

Climate change is already impacting the biology of the oceans and some dependent industries are in turn responding to these impacts. The development of response options for users of marine resources, such as fishers, is important in guiding adaptation efforts. However, harvesting fish is only the first step in a supply chain that delivers seafood to consumers. Impacts higher up the chain have seldom been considered in fisheries-climate research yet an understanding of these impacts and how climate risks and adaptation information are interpreted and used by stakeholders across the chain is vital for developing viable and sustainable adaptation options. We examined stakeholder perceptions of points where climate change impacts and adaptations currently occur, or may occur in the future, across the supply chains of several Australian fisheries (southern rock lobster, tropical rock lobster, prawn) and aquaculture sectors (oyster, aquaculture prawn). We found that climate change impacts are well understood at the harvest stage and there is evidence of potential impacts and disruption to supply chains. Yet, there currently is no strong driver for change higher up the chain. Holistic adaptation planning along the supply chain, underpinned by targeted information and policy for the catch, processing and distribution, and marketing phases is needed. This effort is needed now, as some adaptation options have long lead times, and a delay in adaptation planning may limit future options. Given potential lead times and associated uncertainty, a risk-based approach is recommended with regard to adaptation planning for Australia's seafood sector.

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Climate change risks and adaptation options across Australian seafood supply chains – A preliminary assessment

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ABSTRACT

Climate change is already impacting the biology of the oceans and some dependent industries are in turn responding to these impacts. The development of response options for users of marine resources, such as fishers, is important in guiding adaptation efforts. However, harvesting fish is only the first step in a supply chain that delivers seafood to consumers. Impacts higher up the chain have seldom been considered in fisheries-climate research yet an understanding of these impacts and how climate risks and adaptation information are interpreted and used by stakeholders across the chain is vital for developing viable and sustainable adaptation options. We examined stakeholder perceptions of points where climate change impacts and adaptations currently occur, or may occur in the future, across the supply chains of several Australian fisheries (southern rock lobster, tropical rock lobster, prawn) and aquaculture sectors (oyster, aquaculture prawn). We found that climate change impacts are well understood at the harvest stage and there is evidence of potential impacts and disruption to supply chains. Yet, there currently is no strong driver for change higher up the chain. Holistic adaptation planning along the supply chain, underpinned by targeted information and policy for the catch, processing and distribution, and marketing phases is needed. This effort is needed now, as some adaptation options have long lead times, and a delay in adaptation planning may limit future options. Given potential lead times and associated uncertainty, a risk-based approach is recommended with regard to adaptation planning for Australia's seafood sector.

Introduction

Anthropogenic climate change drivers such as global warming and ocean acidification are modifying the oceans and seas around the world. In Australia, the marine climate is already changing substantially (Poloczanska et al., 2007; Lough and Hobday, 2011), and these trends are projected to continue (Hobday and Lough, 2011). Significant warming of ocean temperatures has been documented on both the east and west coasts (Ridgway, 2007; Pearce and Feng, 2007; Lough and Hobday, 2011). Such changes are in turn impacting coastal marine ecosystems (Ling et al., 2009; Last et al., 2011; Wernberg et al., 2011), by altering the distribution, growth, recruitment, and catch of exploited marine species, and/or their prey and

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predators (Poloczanska et al., 2007; Doney et al., 2012; Poloczanska et al., 2013). As a result, marine resource-based industries, such as fishing and aquaculture, are expected to see both opportunities and losses (Hobday and Poloczanska, 2010) and may need to adjust practices in order to maintain or enhance production. This adjustment is important in Australia and elsewhere as seafood plays an important role in food and economic security (Allison et al., 2009; ABARES, 2011) and supplies about 10% of world human calorific intake (Nellemann et al., 2009; FAO, 2011).

The response of regionally important marine industries such as fisheries to climate change is an area of active investigation. Even though the bio-physical elements of these industries have so far received the most attention (e.g., Hobday, 2010; Cheung et al., 2012), long-term shifts in target species and related changes in fisher activity have been reported from around the world (e.g., Nye et al., 2009; Last et al., 2011; Pinsky and Fogarty, 2012; Hamon et al., 2013) while climate-related extreme events also impact fisheries and aquaculture in the short term (Caputi et al., 2010; Wernberg et al., 2011; Marshall et al., 2013). Planning responses to climate change at all time scales is built on a solid biophysical understanding, yet this alone is not sufficient as the full range of opportunities and threats that will confront fisheries and aquaculture as a result of climate change are not just at the production phase. Consideration of the impacts of climate change along seafood supply chains, the steps a product takes from capture to consumer (Peterson et al., 2000) is vital to safeguard the ongoing supply of seafood.

Supply chains represent a useful construct for examining industries in their entirety, because the success of a chain relies more on the way components are assembled to provide effective delivery than on the components themselves (Peterson et al., 2000). A holistic perspective allows examination of barriers and opportunities that would not be apparent from a focus on a single element, such as the wild fish capture phase. Supply chains can range from complex representations that include all of the scientific, production, commercial, technical, structural, policy and related activities involved in the matching of the product to a consumer need, its production, storage, packaging, marketing, sale and transport, including in-chain and in-store quality management, to simpler, fisher-processor-distributor representations (Peterson et al., 2000; Spencer and Kneebone, 2012).

Formally, adaptation is the process of developing local responses to climate change and a deliberate change in anticipation of, or in reaction to, external stimuli and stress (Adger et al., 2005; Nelson et al., 2007). Adaptation can include both biological (e.g., changing distribution) and social adaptation (e.g., human responses such as fishers moving target locations or switching species) (Marshall et al., 2013). An understanding of how adaptation could occur along the catch and post-harvest elements of the supply chain will complement existing bio-physical knowledge, and inform future planning.

To this end, documenting the potential impacts along the chain and the potential adaptation responses, coupled with integration of the social values or priorities showing which adaptations are favored or limited should improve the effectiveness of response actions. As an example, public perceptions of seafood industries vary in terms of their sustainability, traceability, freshness, cost, and ease of preparation (Sparks, 2011). While current perceptions of sustainability in seafood are primarily focused on proximate ecological concerns (e.g., eco-certification processes such as Marine Stewardship Council, Kaiser and Edward-Jones, 2006), impacts stemming from the material and energetic demands of industrial fisheries can also be substantial (Pelletier and Tyedmers, 2008), and may be of increasing importance to consumers. For example, the capture and landing phase of wild marine fisheries account for about 1.2% of global oil consumption and directly emit more than 130 million tonnes of CO_2 into the atmosphere each year (Tyedmers et al., 2005). Each step along the supply chain adds to the environmental burden with some products travelling thousands of kilometres before final consumption (Grescoe, 2008; Merino et al., 2012). As a result of these factors, improved energy efficiency and mitigation of emissions are therefore likely to be important considerations for fisheries responding to climate change (Hobday and Poloczanska, 2010), In this case, reducing emissions may also improve public perception and result in improved sales at the end of the supply chain.

An integrated assessment of adaptation options that also includes an investigation on social decision making, such as stakeholder perceptions about the changes *per se*, or perceptions about the positive and negative social consequences of changes, is currently lacking in marine adaptation research (but see Marshall et al., 2013 for an exception). There is also a need to understand any cascading effects of climate change mitigation and adaptation strategies along the chain. For example, distributions of harvested fish species have been reported to move poleward as a result of climate change (Last et al., 2011), which can result in reduced abundance at a location. One potential adaptation response to this local change in abundance is a management change to the individual tradable quota (Frusher et al., 2013). This may lead to two seemingly unrelated effects that are likely to have cascading effects: a shrinking in the size of the fleet (Hamon et al., 2009) and fishers taking increasing risks to fish while the price is high (Emery et al., in press). Beyond the capture phase these effects may lead to the need for a change in processing locations or increased supply of new products that need to be marketed in new ways.

For successful adaptation planning and appropriate risk management it is also important to understand if change typically occurs at isolated links in supply chains, propagates, or is integrated. Different motivations and values can drive decision-making at different points in the chain. Thus, responses to climate change that do not consider all aspects of the supply chain may not achieve expected outcomes – continued seafood sustainability – and result in unforeseen risks. Here we address these challenges by examining seafood stakeholder perceptions regarding impacts and risks from climate change and potential adaptation options and barriers along the supply chain of five Australian fisheries and aquaculture industries. This research represents the first step toward more holistic adaptation planning and management of climate risk for this sector in Australia.

Methods and case studies

Case studies

Marine fisheries and aquaculture are economically and socially important industries in Australia. The gross value of commercial fisheries production was estimated at $2.18 billion in 2009–10, of which a growing proportion (~40%) was from the aquaculture industry (ABARES, 2011). Rock lobster, prawns, abalone and tuna are the most valuable fisheries, while salmon is now the most valuable farmed product (42% total value). Australian fisheries are managed and regulated using a combination of spatial management (e.g., geographic regions), input controls (e.g., vessel numbers), output controls (such as individual transferable quotas and total allowable catch) and technical controls (e.g., gear types) (Smith et al., 2007, 2008). To examine adaptation options along the supply chain and across the sector, we selected five case studies of Australian seafood production, representing aquaculture and wild capture fisheries, ranging in production method, value and tonnage produced (Table 1). Southern rock lobster (SRL), tropical rock lobster (TRL), wild caught prawn (wild prawn), oyster aquaculture (SRO) and prawn aquaculture (aqua prawn) span the latitudinal range of Australia and together represent just under $600 million in annual landed value.

Social perception study

Qualitative, semi-structured interviews with 32 stakeholders were undertaken over a three month period in 2012 by the lead author. Contact details were sourced from industry project partners and participants approached via email or telephone with a brief description of the project and an invitation to participate. Stakeholders were selected on the basis of their expertise in the fishery (biological, policy, management, or conservation) and/or their position along a simplified three-step supply chain (fishing – processing and distribution – marketing). For each fishing and aquaculture sector five to seven interviews were undertaken. While this is a relatively small sample size, the expertise of the participants provided sufficient information to draw broad comparisons in subsequent analysis. Although we chose interviewees to allow equal representation in each of the three stages in the simple supply chain, we found that most stakeholders had expertise across multiple stages, and so simple reporting of stakeholder numbers interviewed per category was not possible. This is because a number of the participants were members of consultative groups that co-manage Australian fisheries (e.g., Smith and Smith, 2001). Representative on these co-management committees have different expertise and also knowledge across the supply chain.

We used the simplified three-step supply chain to initiate discussion during interviews, then used the seven-step chain for climate-specific discussion and analyses. While more industry-specific supply chains are available for some Australian fisheries (Comiskey, 2009; Ruello and Associates, 2008; Spencer and Kneebone, 2012), simplified chains facilitated communication during interviews and are therefore appropriate for these initial investigations.

The aim of the interviews was to gather stakeholder perceptions regarding: (1) the supply chain of their fishery; (2) current and potential climate change impacts along the chain; and (3) potential adaptation options to climate change impacts. In addition we also asked participants for their perceptions on the potential for growth in their fishery. Where possible interviews were undertaken face to face but due to of the distribution of participants around Australia the majority of interviews were conducted by telephone. The duration of the interviews was around 30 min. The interviews were recorded and transcribed and subsequently sent to participants for edits if desired. Specific questions were aimed at understanding:

(i) The current supply chain, including;
- patterns in the supply chain of the industry
- flexibility in the supply chain
- risk in the supply chain
- the potential for change and growth
- the way in which (and by whom) change and growth could be driven
- limitations and the causes of change and growth
- ways to overcome the limitations

(ii) The perceived future supply chain, including;
- desirable future changes in the industry

Table 1
Approximate annual size, value and main location of the selected Australian seafood sectors.

Industry	SRL	TRL	Oyster	Aquaculture prawn	Wild prawn
Tonnage	3083 tonnes^	704 tonnes^	14,807 tonnes*	5381 tonnes*	21,619 tonnes*
Value ($A)	250 million+	24 million+	99.8 million*	77.5 million*	246.5 million*
Main states for industry	South Australia, Victoria, Tasmania, Western Australia	Queensland, Torres Strait	South Australia, New South Wales, Tasmania, Queensland	Queensland, Western Australia, South Australia	Northern Territory, Western Australia, Queensland, South Australia

Sources: *ABS, 2012; ^FRDC, 2012; +pers. comm. 2013 Bridget Green and Brett Arlidge.

- enablers and limitations to these future changes
- the support needed to encourage or enable the industry
- policy changes or information needs, and

(iii) The perceived effects of climate change on the supply chain, including;

- perception of climate change and observed/noticeable changes
- perceptions of industry changes as a consequence of climate change
- perceptions of the impact of climate change on industry
- concerns and opportunities arising from climate change
- perceptions of potential adaptations to climate change

Analyses

Climate change perspectives and adaptations as well as general emergent patterns (categories) and themes were identified in the interview data. Interview transcripts were coded using NVivo 9 qualitative data analysis software (QSR International 2009). This type of analysis is based on grounded theory approaches (Strauss and Corbin, 1998; Charmaz, 2006) where theory is derived in a 'bottom up' process, in which codes (descriptive elements) emerge from analysing the collected data. In the analysis process open/initial coding is followed by axial coding to form categories and themes (Charmaz, 2006). To help gain a holistic overview of role of the different stages in the supply chain in the formulation of adaptation options, the interview responses were also categorised by perceived climate and non-climate impacts and adaptations for the different supply chain stages.

Results

Transcripts from the 32 interviews were coded and organised into four themes and 17 categories. The four overarching themes (in order of most discussed) were: Concerns, Limitations, Opportunities and Adaptations (Appendix A). Across these themes, the top categories were costs, legislation and exports and industry strengths (Fig. 1). Climate Climate change was the equal fourth most discussed category (Theme: Concerns) together with competition and industry size. With regard to the themes, adaptations along the chain were less often discussed than the limitations, concerns and opportunities themes.

Industry specific themes and categories

Not all categories had the same relevance in the different fisheries. For instance, the oyster industry mentioned "industry strength" most frequently, illustrating this as a key factor that is perceived to benefit the industry in adapting to climate change (Table 2). Similarly, interviewees from both lobster fisheries (SRL and TRL) and prawn aquaculture most often mentioned cost as a concern that may act as a barrier to adaptation.

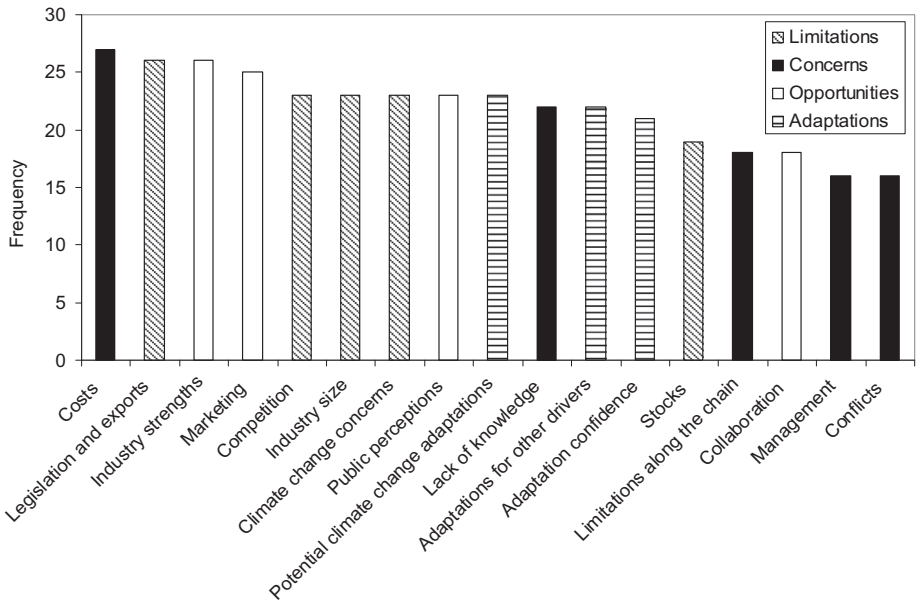

Fig. 1. Frequency of category raised by interviewees (n = 32, maximum of one count per participant) coloured by organising theme, as explained in the text.

Table 2
Comparison of the top eight categories discussed by interviewees. Membership of a particular sector and supply chain position or expertise is noted. Empty cells indicate that the category was not raised as an issue by all interviewees in a seafood sector. SRL: Southern Rock Lobster, TRL; Tropical Rock Lobster.

Category	Sectors rating this as a top issue	Supply chain position[+] or expertise rating this as a top issue	Example quote illustrative of category of response – noting sector and supply chain position of interviewee
Costs	SRL TRL Aqua prawn	Fishing Marketing Conservation	"Bait's dear, our fuel is dear, so we need to get a higher price as well to be able to remain viable." (SRL, Fishing)
Industry strengths	Oyster	Marketing Manager	"I think the diversity of conditions and the diversity of culture methods means that there's a certain degree of resilience already built into the industry." (Oyster, Manager)
Legislation and exports	SRL Aqua prawn	Fishing Manager	"Regulation is probably the biggest restriction." (Aqua prawn, Farmer)
Marketing		Marketing Conservation	"You've got a good product worth a lot of money... and I just don't think that it is being taken advantage of." (TRL, Conservation)
Competition	Wild prawn Aqua prawn	Marketing	"We quite happily import 70 to 80% of our seafood needs here in Australia [although] we've got the capability of doing it ourselves" (Aqua prawn, Marketing)
Industry size	Wild prawn	Fishing	"That is one of their other problems too, is getting good crew. It's more and more challenging simply because the better seamen have been snapped up in the oil and gas industry." (Wild prawn, Fishing)
Climate change concerns		Manager Conservation	"When you start talking about the fishery and this warmer water and large amounts of mortality in the warmer waters, that could become more frequent." (TRL, Manager)
Public perceptions	Oyster	Marketing Fishing	"There's another risk that the market doesn't value an oyster – they're looking for smaller and smaller oysters because they're driven by the price point rather than the size and the quality of an oyster." (Oyster, Marketing)

Note: The production stage of supply chains is noted here as "fishing" for both fishers and aquaculture farmers.

Southern Rock Lobster stakeholders mostly reported issues within the coding categories costs, and legislation and export (Table 2). Important issues for many interviewees were the changing structure of the harvest industry. More specifically respondents mentioned a decrease in business viability, a fall in the number of participants because of an ageing fishery workforce, prohibitive start up costs (in terms of the cost of equipment and quota), and variability and potentially long term decreases in wild lobster stocks. At the market end of the supply chain, reliance on exports to the Chinese market, tariff compliance and impacts of currency were the most identified issues.

Tropical Rock Lobster (TRL) stakeholders also mostly reported cost-related issues (Table 2) but also raised the complexity of management arrangements in terms of sharing stock with Papua New Guinea and in terms of different lifestyle objectives of fishers. Many issues raised for the TRL related to the harvest end of the chain, including potential declines in available wild lobsters. The potential competition from lobsters sourced from Asian aquaculture businesses was raised. However, the impact of aquaculture increase on the wild TRL fishery could be offset by reductions in SRL stocks, thus keeping demand high for wild product. The need to increase industry-wide production of high value live product versus low value frozen tails, and thus increase the value of the fishery, was another issue commonly discussed.

Most oyster industry respondents saw opportunities for growth in the public perception category (Table 2). Many oyster industry issues related to the harvest end of the chain. For instance, of concern were disease threats such as POMS (Pacific Oyster Mortality Syndrome) as recent outbreaks have devastated oyster farms in Europe. In response to the disease threat oyster industry respondents specifically focused on breeding for disease resistance. The complex nature of the oyster industry in terms of its remote location and diverse business structure was seen as a potential impediment but also offering the potential for flexibility. Regulatory limitations on land use or suitability of alternative lease areas were raised as concerns.

Aquaculture prawn stakeholders mostly reported issues in the costs, legislation and exports categories (Table 2). In particular, concerns about regulations that limited industry expansion were similar to those of the oyster aquaculture industry. Energy costs and infrastructure limitations that were raised were mostly associated with the harvest end of the chain. The prawn aquaculture industry also raised marketing issues related to product awareness, imports and product substitution.

Interviewees from the wild caught prawn industry were predominantly concerned with competition issues and the decreasing size of the industry (Table 2). The viability of fishing was raised in the context of increased costs with fuel price increases and marine park exclusions. The industry had recently undergone some major restructuring, downsizing the number of vessels and rearranging management, and some interviewees felt this left the industry in a strong position for future challenges.

Climate change and the supply chain

Climate change issues were also discussed in the interviews regardless of whether respondents acknowledged anthropogenic climate change. According to interviewees, climate change was perceived as a strong driver for the seafood industry,

but was not the sole driver of change. A range of observations of change were reported and included increased frequency or severity of coral bleaching, sea level rise, increased water temperatures, species distribution change, increased catches of some species, changed currents, and changes in the food supply of certain species.

Some changes, such as warming ocean waters, were perceived as potentially having a positive impact on the industry (e.g., (SRL, TRL, wild caught prawn, aquaculture prawn) due to expected increases in growth rates, growing seasons or catch sizes. Interviewees in the TRL and wild prawn sectors felt that increases in tropical water temperature will be gradual and that resilient species will be able to adapt at the biological level. The perceived climate change issues were linked to the stages in the seven-step supply chain (Table 3). The direct impacts of climate change (extreme weather events, changes in stocks location and volumes, and increased temperature) were perceived to most impact the harvest end of the supply chain (Table 3). In particular, extreme weather events were perceived to have a negative impact and to be already occurring more frequently. In contrast, changes to fishing or harvest seasons were seen by stakeholders as likely and needing to be prepared for, and likely to be positive. The impacts were also perceived to occur over different time scales, although interviewees were vague with regard to this aspect. The indirect impacts of climate change included increased fuel costs, energy use, and disease, and were again mainly perceived to impact the harvesting end of the supply chain (Table 3).

With regard to potential adaptation options, there were perceived to be opportunities in all stages in the supply chain although higher numbers of responses were recorded for adaptations in harvesting activities compared with retail and wholesale stages (Table 3). One issue that was identified across all stages of sectoral supply chains was a need for increased collaboration. It became apparent in the interview process that some potential impacts of climate change are not yet well understood, particularly social aspects, carbon price increases and viability thresholds, and options for individuals to change industries. Similarly, uncertainties related to biological impacts were raised, more specifically, the impacts of increased temperatures on stages of development of target species, the effects of changed ocean currents, the effect of changing pH levels, and regional variability in the effect of a change in the frequency of extreme events. As a consequence of these uncertainties some respondents felt that adaptation strategies could not be developed at this stage.

The interviews also revealed perceptions regarding barriers to change – for example, the lack of understanding or awareness of climate impacts, perceptions of ability to change, regulation limitations, industry size or dynamics limiting capacity to collaborate or fund programs. Even though these barriers are complex and difficult to resolve, interviewees noted multiple factors that are positive for the future, notably the high quality of the seafood products, high demand for seafood, strong perceptions of sustainability within the industries, the proactive nature of the industries, and the availability of research support (Appendix A).

Discussion

There is a growing awareness in many climate-exposed primary industries or businesses of the vulnerabilities of supply chains to risks and potential costs associated with the physical and regulatory impacts related to global climate change (Linnenluecke et al., 2011; Jira and Toffel, 2012). In the wine industry, for example, some adaptation responses were found to be dependent on other changes along the chain (Soosay et al., 2012), emphasising the need for holistic planning.

In Australian fisheries and aquaculture much concern around climate change is focused on the capture phase (Frusher et al., 2013). The pre-occupation with the capture phase of the supply chain mirrors the focus of scientific research and literature as well as mainstream media. This narrow focus does not reflect the broader importance of the post-harvest supply chain for delivery of the seafood product to consumers. In this study, the categories marketing, product description and public perception were often related to climate change and relevant to different stages of the supply chain, demonstrating the need for a broader consideration of the supply chain when responding to future climate risk.

The focus on production-related impacts of climate change is likely to be associated with the ecological nature of most observations of climate-related change identified during interviews. The ecological observations are most easily linked to the capture phase of fisheries (Nursey-Bray et al., 2012; Frusher et al., 2013). Impacts further along the supply chain were considered by stakeholders to be indirect effects and were also regarded as less certain. This uncertainty presents a dilemma for effective adaptation, as actions to manage risk from uncertain outcomes may be delayed until the effects become clearer. However, there are risks associated with inaction, and in particular, opportunities may not be realised. Holistic adaptation planning along the supply chain, underpinned by targeted information on climate risks for the non-harvest elements is thus crucial. A holistic approach to planning may reduce risk as adaptation options higher up the chain often have long lead times (e.g., Linnenluecke et al., 2011; Soosay et al., 2012), therefore a delay with regard to adaptation planning may limit future options. Personal experiences with extreme events can also have important effects on climate change perceptions (Weber, 2011) and may indeed increase the likelihood of bringing forward adaptation activity (Linnenluecke et al., 2011; Marshall et al., 2013).

While implementation of some adaptation activities need not be delayed as they are win–win options (e.g., Grafton, 2010; Bell et al., 2013), the timeframes for climate adaptation are much longer than strategies that are more commonly implemented by the seafood industry (e.g., marketing campaigns, green certifications). Existing strategies are not only over shorter timeframes but can also be undertaken by a single component of the chain, and thus do not require collaboration with other parts of the chain. This is perhaps one reason why, in many businesses and industries, collaboration and developing options for climate change adaptation is not occurring along the chains. As a result, adaptations may also not be easily implemented.

Table 3
Climate change impacts, adaptations and supply chain activities discussed by interviewees across all seafood sectors. The perception of impact can be positive (+) or negative (−) with impacts occurring now, or in the future.

Code from analysis	Perception of impact (+) and/or (−)	Perception of timing of impact	Number of interviewees raising the issue for each supply chain activity							Total number of interviewees raising the issue (%). See note
			Capture	Transport	Storage	Processing	Wholesale	Retail	Consumer	
Direct climate change impacts										
Extreme weather events.	−	Occurring	8	1						9 (28%)
Changes in stock locations.	+, −	Potentially occurring	8							8 (25%)
Changes in stocks (volumes, seasons, speed of growth).	+, −	Occurring	7							7 (22%)
Increased temperature.	+, −	Occurring	1	1	2					3 (9%)
Indirect climate change impacts										
Rising fuel and energy costs.	−	Occurring	13	4	1	1				16 (50%)
Increased incidence of disease.	−	Potential to occur	8							8 (25%)
Increased energy use.	−	Occurring	1							1 (−)
Potential climate change adaptations										
Change industry structure (number of operators, licenses)	+, −	Potentially occurring	17	1		2				17 (53%)
Improve marketing (labelling, information, increase appeal)	+	Potentially occurring	1			3		10	8	16 (50%)
Improve fuel efficiency (vessel efficiency, reduce transport links, more targeted fishing/transport times, fuel)	+	Potentially occurring	9	1		1	1			12 (37%)
Monitor/model impacts (acidification, sea level, rainfall, salinity, disease)	+	Potential to occur	9		1					9 (28%)
Breeding programs	+	Potentially occurring	8							8 (25%)
Increase collaboration across supply chain	+	Potential to occur	3	2	1	1		1	1	7 (22%)
Change locations	+, −	Potentially occurring	6							6 (19%)
Change season times	+	Potential to occur	5		2	1				6 (19%)
Product enhancement (certification, accreditation)	+	Potential to occur							6	6 (19%)
Change species	+, −	Potential to occur	4					1	1	5 (16%)
Change fishing/ harvesting options (growing cages, raising racks, new techniques, by-catch)	+	Potential to occur	5							5 (16%)
Change storage options (grow out in tanks, overseas storage)	+, −	Potential to occur			4					4 (12%)

(*continued on next page*)

Table 3 (*continued*)

Code from analysis	Perception of impact (+) and/or (−)	Perception of timing of impact	Number of interviewees raising the issue for each supply chain activity							Total number of interviewees raising the issue (%). See note
			Capture	Transport	Storage	Processing	Wholesale	Retail	Consumer	
Change marketing (new markets, new products)	+	Potentially occurring				1		3		4 (12%)
Use alternative energy	+	Potential to occur	3					1		3 (9%)
Improve energy efficiency	+	Potentially occurring	2			1				3 (9%)
Improve water efficiency	+	Potentially occurring	3							3 (9%)
Potential adaptations for other drivers and policy issues										
Improve public awareness and information (species differentiation, sustainability)	+	Potentially occurring	5					1	16	20 (62%)
Simplify/overcome regulations (development restrictions, number)	+	Potential to occur	15		1		1			17 (53%)
Support training and accreditation and next generation workers	+	Potential to occur	12							12 (37%)
Match demand	+	Potential to occur	3	1	1			1	4	10 (31%)
Increase focus on live	+	Potentially occurring	7	1	5					9 (28%)
Reduce reliance on wild catch (spat/ stocks, feed)	+	Potentially occurring	9							9 (28%)
Clarify fishery objectives to minimise conflict or confusion	+	Potential to occur	6							6 (19%)
Increase exports	+, −	Potential to occur	1						3	4 (12%)
Total times activity discussed			179	12	18	11	2	18	39	

Note: In the total number of people raising the issue column, one person may discuss several activities so the numbers may not sum to match the final column.

Collaboration has long been recognised as a driver for sustainable competitive advantage (Fearne et al., 2012; Soosay et al., 2012) and is contingent on mutual trust and commitment. As climate change perspectives are rooted in belief systems and values (Kahan, 2010) collaborative adaptation across chains is not a simple task; it requires a 'cultural fit'. Developing a 'cultural fit' may aid collaboration as it helps establish clarity, acknowledgement and acceptance of different values from people at different points in the chain who are working towards some shared values and a shared sense of purpose (Nir et al., 2011). Developing a shared understanding and sense of purpose relies on commitment from industry stakeholders to participate and work together in good faith and for mutual benefit, across different elements of the supply chain. This may require dedicated research efforts to connect actors along the supply chains (e.g., Hobday et al., 2013).

An important finding was that seafood industry participants generally felt there was considerable potential for constructive adaptation options to be developed in their sectors. These options included, for example, improving fuel efficiency, conducting breeding programs, altering the structure of the industry, simplifying regulations and improving public awareness. There are also opportunities for advances in monitoring or modeling key impacts of climate change along supply chains. Stakeholders emphasised that there are a number of external drivers that need to be managed alongside climate risk in developing adaptation options. It is clear that climate change is inextricably linked with other drivers of change, such as consumer demand. In Australia, seafood supply chains can also rely on imported product for the domestic market while seafood exports mainly include the most valuable products (Spencer and Kneebone, 2012). Therefore the value of the Australian

dollar, import/export regulations, trade relations and transport options all impact adaptation decisions (Norman-Lopez et al., 2013). Similar observations of drivers of change have been reported from other primary industries such as agriculture (Marshall, 2010; Hogan et al., 2011), where individuals have a range of views of climate change and there remains uncertainty about impacts and adaptations, requiring monitoring, further research and evaluation (Buys et al., 2012).

Policy can guide climate adaptation at many points along a supply chain. In the seafood industries examined here, climate impacts and possible adaptation options along supply chains are not well documented, and therefore it is likely that policy makers are not well informed regarding policy barriers and opportunities. From the perspective of resource users, several key policy areas need to be addressed to improve business performance and support climate change adaptation. These include adjusting current policies at the harvest stage of the supply chain and supporting holistic planning. There is room for improvement at the harvest end of supply chains with regard to better definitions, weightings and/or prioritisation of management objectives for individual fisheries and the sector as a whole; simplification and modernisation of regulations; and more support for recruitment of skilled workers, and training and accreditation. Specific examples of policy-related barriers include restricted access to international markets due to trade agreements (rock lobsters into China), closed seasons for harvest that coincide with high price periods for product (rock lobster) (Hobday et al., 2013), and water quality regulations that limit industry expansion (aquaculture prawn).

Overall, taking a supply chain perspective for the seafood sectors examined here showed that industry participants perceived opportunities and barriers for climate change adaptation across most of the chain, but in particular saw more options for the production end of the chain. Whilst the production end of the chain might deserve such attention, adaptation planning is unlikely to be successful unless all links in the supply chain are considered. The need for increased understanding of the ecosystem impacts of climate change, and for flexibility and resilience across the chain is paramount. Improved collaboration along supply chains through more communication and transparent interactions, as well as improved marketing, will underpin future adaptation and the ongoing supply of seafood even if biological production declines for some species.

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Appendix A.

Analysis hierarchy: themes, categories and codes (frequency is the number of times coded across all interviews).

Theme (frequency)	Category (frequency)	Codes (frequency)
Concerns (308)	Legislation and exports (105)	Identifies limits of regulations (31)
		Discusses the role of policy (15)
		Discusses illegal trafficking (13)
		Discusses reliance on China (13)
		Discusses currency (11)
		Discusses increasing export (10)
		Expresses a view that there are too many regulations (8)
		Comments on land use regulation (4)
	Climate change concerns (80)	Expresses a concern about climate change (38)
		Makes a physical observation of climate change (19)
		Discusses extreme events (17)
		Discusses weather vulnerability (15)
	Industry size (69)	Discusses changing industry structure (35)
		Discusses the next generation of workers (21)
		Advocates the need for more training (10)
		Comments on the need for highly skilled divers (3)
	Competition (54)	Discusses sources of competition (24)
		Discusses imports (15)
		Discusses product substitution (9)
		Comments on marine parks (6)
	Stocks (50)	Discusses problems of disease (25)

(*continued on next page*)

Appendix A. (*continued*)

Theme (frequency)	Category (frequency)	Codes (frequency)
		Discusses reliance on wild caught (9)
		Expresses a sustainability concern (6)
		Identifies limits to growing production (5)
		Discusses mortality of target species (5)
Limitations (297)	Costs (96)	Comments on price driven nature of industry (21)
		Comments on fuel costs (20)
		Raises concern about viability (18)
		Comments on production costs (9)
		Comments on the carbon tax (7)
		Discusses cash flow limitations (7)
		Discusses high energy use (6)
		Comments on freight cost (5)
		Comments on start up costs (3)
	Management (67)	Raises an issue with quota (18)
		Supports implementation of quota (13)
		Discusses timing of seasons (11)
		Identifies a management failure (11)
		Discusses allocation of licenses (9)
		Discusses management of shared stock (5)
	Limitations along the chain (59)	Discusses transport limitations (24)
		Identifies marketing limitations (18)
		Identifies a lack of transparency in chain (7)
		Discusses storage limitations (4)
		Identifies supermarket limitations (4)
		Discusses packaging limitations (2)
	Lack of knowledge (44)	Expresses uncertainty about climate change (21)
		Identifies areas where scientific investigation is needed (16)
		Discusses modeling flaws (5)
		Identifies a lack of understanding of the system (2)
	Conflicts (31)	Identifies a clash of objectives (11)
		Discusses the effects of actions of others (10)
		Identifies barriers to collaboration (5)
		Identifies a sustainability conflict (5)
Opportunities (280)	Industry strengths (88)	Expresses confidence in the sustainability of industry (27)
		Identifies the industry as proactive (24)
		Comments on fishing lifestyle values (16)
		Identifies the flexibility of industry (11)
		Comments on the high quality of product (10)
	Marketing (83)	Discusses marketing potential (22)
		Discusses marketing initiatives (17)
		Discusses markets other than China (12)
		Discusses demand for product (12)
		Identifies areas for product enhancement (7)
		Discusses potential new products (5)
		Discusses generating new markets (4)
		Discusses fluctuations in demand (4)
	Public perceptions (71)	Comments on public perceptions of industry (46)
		Identifies the need for knowledge building (13)
		Discusses restaurant use of product (6)
		Discusses consumer product preferences (6)
	Collaboration (38)	Advocates collaboration (20)
		Advocates co-management (10)
		Discusses industry funding arrangements (5)
		Advocates a trade agreement (3)

Appendix A. (*continued*)

Theme (frequency)	Category (frequency)	Codes (frequency)
Adaptations (199)	Potential climate change adaptations (79)	Advocates breeding opportunities (26)
		Advocates improving efficiency (18)
		Discusses alternative energy options (12)
		Discusses changing location (11)
		Discusses changing species (10)
		Discusses translocation (2)
	Adaptations for other drivers (66)	Advocates increasing live production (28)
		Discusses water management (11)
		Advocates feed sustainability opportunities (8)
		Discusses holding time (8)
		Comments on food safety (4)
		Discusses use of growing cages (3)
		Discusses nutrient release (2)
		Gives examples of diversifying income (2)
	Adaptation confidence (54)	Expresses confidence about adaptation to climate change (25)
		Views climate change as a lower priority than other drivers (14)
		Views target species as resilient (8)
		Comments on the potential for increased stock (7)

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