RETRACTION
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PACIFIC CONSERVATION BIOLOGY

Retraction notice to 'Key research priorities for the future of fish and fisheries in Australia' [Pacific Conservation Biology (2022) doi: 10.1071/PC21073]

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After due consideration of issues raised with respect to this paper, the Editor-in-Chief and the authors agree to retract the paper from *Pacific Conservation Biology*.

Reason: The paper includes modest amounts of text nearly identical to text in a prior publication. An editorial review panel also deemed that the paper is ambiguous in places in distinguishing between the original contributions of the study and that of prior work. These problems apply at more than one point in the paper, making it difficult to deal with them by publishing a correction. Therefore retraction, with the option of submitting a revised paper for review and potential publication, offers the clearest resolution. The authors regret and apologise for any inconvenience this may have caused.

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Key research priorities for the future of fish and fisheries in Australia

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ABSTRACT

Context. In Australia, the health of our marine, estuarine and freshwater fishes are of critical importance. The aquatic and marine ecosystems, and the fishes that occupy them each have an important role in our country's ecological, economic, cultural and social wealth. Climate change, resource over-exploitation, invasive animals and diseases, and habitat degradation are just a few of the burgeoning threats that researchers and managers must address to ensure the prosperity of Australia's natural fisheries resources. In addition, differences in legislative frameworks among jurisdictions hinder our ability to coherently manage fish resources at scales that are relevant biologically, ecologically and socially. **Aims.** Here, we identify the key research priorities for fish and fisheries research in Australia, across seven thematic fields of study. **Methods.** Research priorities were evaluated using a horizon-scanning approach, which identified research questions related to the field of fish and fisheries research in Australia. **Key results.** A total of 284 questions unique research questions were categorised and prioritised, resulting in the formation of the top 10 highest priority research questions across each of the seven themes. **Conclusions.** The outcomes from this work can be used to directly complement ongoing work from research providers working in the field of fish and fisheries as well as the development of new areas of research. **Implications.** The priorities identified will enable researchers and policy makers to identify critical knowledge gaps, develop collaborative research programs, investigate novel approaches, and to improve transparency around decision-making processes.

Keywords: assessment, biodiversity, biosecurity, climate, emerging technologies, environment, monitoring, resource management.

Introduction

Fish and fisheries are broad terms relating to the biology and ecology of aquatic fauna and the anthropogenic activities associated with catching or 'fishing' for these taxa. Australia has the world's third largest fishing zone, covering over 8 million square km (McPhee 2008). Within this area reside some of the most biodiverse areas on the planet, such as the Great Barrier Reef and Ningaloo Reef, which are complemented by an extensive inland network of freshwater systems that link to estuaries and coasts (Butler *et al.* 2010). Despite this richness of species and ecosystems, Australian waters are overall considered to be nutrient poor when compared to many other areas of the world, and as a result are typified by lower species biomass (McPhee 2008). This low biomass is reflected in Australia's wild caught fisheries production, which does not rank among the top 60 nations worldwide (McPhee 2008; FAO 2021). However, not all fishing in Australia can be measured by production, with fisheries interactions ranging from extractive commercial or recreational fishing, to traditional fishing for cultural purposes or recreational fishing for catch and release. In addition, not all threats or interactions are related to fishing activity, with climate change, pollution, habitat destruction and invasive species representing major threats to fish species or the ecosystems they occupy (Kingsford *et al.* 2009; Arthington *et al.* 2016). The broad geographic area along with the great diversity of fish and fisheries in Australia presents considerable challenges for researchers working in the region when designing focused questions that will generate information that matches the needs of policy makers.

The identification and coordination of research needs varies throughout Australian fish and fisheries landscape, with the competing priorities spread across an ecologically diverse continent. Avenues for research funding include national competitive grants programs, philanthropic foundations, community grants, statutory bodies and direct government funding. Each funding agency has their own approach for identifying research priorities related to their species, ecosystem, area or stakeholder of interest. The result of this is that many organisations prioritise research towards achieving their specific policy or organisational objectives, while some national competitive grants programs may not list dedicated research priorities at all, and instead have a much broader remit, with the aim of supporting research based on knowledge, innovation and research impact. In contrast, Research and Development Corporations are the most structured organisations and have state-based research advisory committees, which engage with stakeholders to seek advice on priorities and investment relevant at the state level. However, their area of responsibility is broad, and competing priorities remain among the stakeholders, organisations and jurisdictions involved in identifying priorities and seeking research funding. While the approaches from across the agencies are complementary, there remains opportunity for identification of targeted research priorities to help overcome issues facing fish and fisheries resources on a national scale.

The use of horizon scanning to identify research needs is becoming common place across many broad disciples of research (Sutherland *et al.* 2011). The advantage of horizon scanning is its ability to provide a platform to bring policy makers and academics together for identifying issues that may be of emerging importance. As a result, it has recently been used in the examination of broad-scale opportunities for furthering recreational fishing, environmental science and conservation initiatives (Sutherland *et al.* 2011, 2020; Holder *et al.* 2020). This method has also been used to identify important topics that are of interest at the jurisdictional level, such as marine science in New Zealand (Jarvis and Young 2019). Horizon scanning approaches also have the benefit of individual research priorities being less influenced by organisational bias, as participants are encouraged to provide input based on their personal experience or preferences, rather than organisational needs (Provencher *et al.* 2020). This independence is fundamental to providing future direction for overcoming issues, which may be associated with political sensitivities or may seem too large to overcome in a single funding cycle. Despite the noted efficacy of horizon scanning it has not yet been applied in Australia, or with a sole focus on fish and fisheries.

We used horizon scanning to identify a list of priority research questions that could be used to inform the future direction in fish and fisheries research in Australia, with the goal of highlighting opportunities that are translatable into applied outcomes. Input was sought from a diverse range of stakeholders that are actively working in the space of fish (biology, ecology) and fisheries (science, assessment, policy, management) in Australia. These included policy makers, teaching and research academics, researchers and members of non-government organisations.

Materials and methods

Participants

An initial list of 35[illegible] emails was collated via a search of academic and grey literature, as well as reports, resources, and online staff listings of relevant organisations. Email invitations were sent out to every contact on this list, with a link to the horizon scanning exercise. The horizon scan was also promoted among organisational mailing lists such as the Australian Fisheries Management Forum to further maximise reach and uptake. Both the initial gathering of questions and later prioritisation exercise, were completed through online surveys. Individuals and institutions were not identifiable in this research. This research was approved by the University of Queensland office of research ethics (permit # 20169002497).

Gathering the initial list of research questions

Participants were invited to submit up to three research questions that they viewed to be the most important for 'informing the future direction of fish and fisheries science or management in Australia to ensure we can adequately conserve and manage our environments and resources'. Submitted questions were required to meet the following criteria to be included in the final list: (1) be relevant to fishes (all taxa) and fisheries in Australia; (2) address an important gap in knowledge; (3) be formulated as a research question (rather than general topic or priority area); (4) be answerable through a realistic research design; and (5) be of a spatial and temporal scope that could be addressed by a research team.

The online survey was launched on 4 October 2019, and was open for 8 weeks. Once submissions were received, they were evaluated against the inclusion criteria, and similar entries were combined to avoid replication These questions were then classified into seven major 'themes' based on similarity of topics across the submitted questions and the ease of use of the final results. Themes were identified to ensure both consistency with relevant literature (Jarvis and Young 2019; Holder *et al.* 2020), and direct relevance to fish and fisheries science or management in Australia. Classification was undertaken through independent allocation of each question to a single theme by co-authors. For any questions that were not consistently classified among co-authors, their intent was first discussed before allocation to the theme deemed as most suitable. The full list of submitted questions is available as Supplementary material.

Prioritising questions for the final list

At the end of the initial question-gathering survey, participants were offered the opportunity to indicate whether they would like to take part in prioritising the final list of research questions. The prioritisation exercise was open for 4 weeks from 23 April 2020. Participants scored questions from zero priority (0), to highest priority (6), using a seven-point Likert scale (zero priority, low, medium-low, medium, medium-high, high, highest priority). Responses were then collated and averaged across participants to identify the 10 highest priority questions for each of the seven themes. The top 10 research questions presented for each theme are listed in priority order with the highest ranked question (highest average score) listed first.

Results

A total of 284 questions were submitted by 103 respondents from across all Australian states and territories. The occupational groups of study participants consisted of policy makers (17%), researchers (52%), academics/educators (16%) and others (15%). The latter category included advisors for community and Indigenous ranger groups, science illustrators and consultants. After evaluation against the inclusion criteria, and combining of similar entries a final list of 228 questions were deemed for inclusion in the prioritisation process. The questions were well distributed across all of the themes as follows: biosecurity (n = 18); resource management and stewardship (n = 30); ecosystem and biodiversity (n = [illegible]); fisheries management (n = 38); monitoring and assessment (n = 39); environment and climate (n = 49); and emerging technologies, tools and approaches (n = 26). A total of 56 individuals from a range of occupational grounds including policy makers (23%), researchers (40%), academics/educators (25%) and others (12%) participated in the prioritisation survey phase.

Theme 1: biosecurity

Generally speaking, biosecurity is concerned with stopping introduced species from establishing and spreading into non-native habitats, or minimising their impact on other species and environments when they do. The overall impacts of invasive species are mediated through complex biotic and abiotic interactions that occur habitat-wide, often altering ecosystems and community assemblages irrecoverably (MDBC 2004; Harris 2013). Within aquatic environments, impacts by invasive species may include habitat destruction and localised extinctions of native plant and animal species, reductions in biodiversity, the introduction of disease and parasites, and economic changes to fishing and tourism industries. Recent research has indicated that the introduction of invasive species poses a higher risk to threatened species than other anthropogenic factors such as agricultural or human disturbance, ecosystem disturbance, pollution or even climate change (IPBES 2019; Kearney *et al.* 2019). Management of aquatic invasive species is particularly challenging due to constraints on effective detection, monitoring, and subsequent eradication activities in aquatic systems. Indeed, the detrimental effects of non-native species introductions have been cited as a contributing factor in 68% of North American fish extinctions in the past 100 years, and an instrumental factor in the threatened status of up to 55% of Australian endemic freshwater fishes (Miller *et al.* 1989; Wager and Jackson 1993; Lintermans 2013). The past 50 years has seen many new establishments of non-native fishes into Australian waters, especially in the warmer northern regions of Queensland, the Northern Territory and Western Australia (Millington *et al.* 2022). García-Díaz *et al.* 2018), attributed these primarily to the either deliberate or accidental release by ornamental fish keepers. In aquatic environments, once established in the wild, invasive fishes are very challenging to eradicate, with methods limited to applying pesticides to entire water bodies and subsequently destroying all local fish and invertebrates in the process (Sandodden *et al.* 2018). Once an invasive fish has naturalised, there may also be larger ongoing costs associated with mitigating their spread, including funding alternative measures of containment (e.g. installing fish screens), conducting long term fish-down activities, and providing industry subsidisations. The environmental cost can rarely be quantified.

The 'silent' invasion of exotic parasites, diseases, and hitchhikers that both reside within the non-native species introductions, and those that arrive by other means (e.g. ship ballast water, fish feed, etc.) have the ability to cause widespread economic losses to Australian aquaculture faming revenue (McNamara *et al.* 2015). Many marine-based biosecurity pathways have been identified via imported feed product, such as Sardine Herpes Virus (through import of American sardines to feed tuna in South Australia (Whittington *et al.* 2008)), and White Spot Syndrome Virus (WSSV) (through the use of infected 'retail' prawns being used as bait (Knibb *et al.* 2018)). In addition to fishery and aquaculture economic losses, secondary impacts from the loss of basal species such pilchards and prawns has resulted in increased mortality of piscivorous seabirds such as penguins (Dann *et al.* 2000) and Australasian gannets (Bunce and Norman 2000), causing significant food web disruptions. The key research questions identified under the biosecurity theme were:

1. How do we develop methods to empirically measure the impact of aquatic invasive animals in Australian freshwater ecosystems?
2. How can we improve the detection of important diseases in shipments of fish, crustaceans or mollusc products imported into Australia?
3. What changes to community assemblages are occurring in native and invasive biota, and how do we know without baseline data?
4. Is the regulatory regime controlling the import of fish/aquatic species into Australia adequately managing the risk of invasive aquatic species into aquatic ecosystems?
5. How can freshwater species and associated ecosystems be better protected from illegal fish imports?
6. What threat do non-native invasive ornamental fish already in Australian households pose to degraded and threatened ecosystems if released?
7. Are compliance and enforcement regimes adequately resourced and utilised to ensure the minimisation of risk of exotic species establishing in our aquatic ecosystems?
8. Is the current Australian compliance regime in place adequate to ensure native freshwater species are protected from illegal invasive fish?
9. How can we improve the laboratory capacities nationally for detection and verification of diseases in aquaculture and wild fisheries?
10. How can we prepare to ensure that native freshwater fish populations recover maximally afterwards if the carp herpes virus is released?

Theme 2: resource management and stewardship

Resource management and stewardship is focused on the application of community-led or voluntary initiatives, rather than strict regulatory approaches to management. There has been increasing interest in habitat rehabilitation as a form of stewardship and management in Australia, with a focus on how different stakeholder groups or agencies can collaborate (Rogers *et al.* 2018; Emslie *et al.* 2020). The co-management of fisheries resources between stakeholders and government is one area where stewardship has advanced and resulted in a shift in governance and management of the resource (Zacharin *et al.* 2008). These community led co-management arrangements have been shown to provide mutual benefits such as greater flexibility to allow for adaptive management under changing environmental conditions and reduced regulatory burden (i.e. red tape) (Nursey-Bray *et al.* 2018). In addition to this, traditional forms of resource management and stewardship, such as voluntary codes of practice or regulatory management, continue to evolve in order to deal with new challenges (e.g. anthropogenic pressures from population growth and urbanisation). However, the lack of information on the effectiveness of different approaches at achieving their outcomes has continued to stifle some enterprises through inadequate community buy-in or lack of government investment in both small- and large-scale initiatives. The key research questions identified were:

1. To what extent does habitat loss and degradation affect the productivity of fisheries?
2. How can links between the health of key habitat and fish stock abundance lead to more effective policy and management decisions at Federal, State and Local Government levels?
3. How can resource management be implemented in a way that adapts to extreme climate events (e.g. heat waves)?
4. How can we improve management and restoration of coastal wetlands to support fisheries production?
5. How can fish and aquatic ecosystems be managed in a way that balances with natural resource requirements of humans (e.g. for water)?
6. How do Australian resource managers prioritise sustainable development over development at all costs?
7. What impact have barriers across inland and coastal waterways had on offshore fish productivity?
8. What are the primary reasons that policy makers do not use scientific advice?
9. How can management of recreational fishing adapt to issues of population growth and cultural change?
10. What are the opportunities for carbon and nutrient trading as a framework for promoting aquatic, estuarine and marine habitat restoration?

Theme 3: ecosystem and biodiversity

In the Anthropocene age of decreasing biodiversity and continuing global changes, maintaining ecosystem function is seen as a means to both preserve biological diversity and secure the services that ecosystems provide to safeguard human wellbeing into the future (Jax 2010). The concept today is prominent in many fields of ecology and conservation biology, such as biodiversity research, ecosystem management, or restoration ecology (Jax 2010). Despite the accelerating loss of species and key ecosystems, research focused on experimental marine biodiversity and ecosystem function lags far behind other areas, and constitutes only a fraction of the total number of studies (Gustafsson and Boström 2011). The paucity of available research is the same in freshwater and estuarine ecosystems, many of which support critical juvenile fish habitat and are particularly vulnerable to anthropogenic impacts such as nutrient loading (including agricultural run-off), industrial and urban pollution, habitat fragmentation and mangrove clearing (urbanisation), among other pressures. In the marine environment, ecosystem based fisheries management approaches have been promoted since the turn of the century, yet despite the strong support for the concept, challenge associated with its implementation have restricted its uptake (Patrick and Link 2015; Lidström and Johnson 2020). There is currently an inadequate understanding of the consequences of these environmental changes and their interactions with other stressors, especially at the higher, multi-species, organisational levels (Belgrano *et al.* 2015). The key research questions identified under the ecosystem and biodiversity theme were:

1. What level of habitat rehabilitation is necessary to have significant positive impacts on fish populations?
2. To what extent does habitat loss and degradation affect ecosystem function?
3. Can recruitment of native freshwater fish species be improved through habitat restoration?
4. What methods are most effective to promote successful shoreline ecosystem restoration (e.g. mangroves, saltmarshes)?
5. How can we halt the loss of biodiversity in freshwater ecosystems in the face of climate change and associated changes in land use and demand for water?
6. How will extreme weather events and sea level rise impact on intertidal fish habitats and vegetation?
7. What are the relationships between fisheries and coastal estuarine mangrove habitats?
8. What are the thresholds of riparian restoration necessary to elicit a strong positive change in native freshwater fish assemblages?
9. What are the ecosystem-level impacts of commercial fisheries and associated bycatch on the Great Barrier Reef?
10. How can marine protected areas be used to maintain functionally resilient ecosystems?

Theme 4: fisheries management

Within Australia, fisheries resources are monitored, assessed and managed at the international, domestic, state and local level depending on the relevant area, species, stakeholders, habitats, ecological communities or impacts involved (Haward 1995; Vince 2018). These varying forms of governance each have different legislative and policy frameworks that align to their organisational objectives for meeting the principles of ecologically sustainable development (Vince 2018). This multi-layered system is complex, with a range of formal (e.g. offshore constitutional settlement arrangements between state and territory governments with the Commonwealth) and informal arrangements (e.g. plans for community level monitoring of resources by state and local government) (Haward 1995). Australia also has a number of statutory authorities that are set up to perform functions related to complex interjurisdictional resources, which aim to integrate resource management across jurisdictions (e.g. the Murray Darlin Basin Authority) (Koehn 2015).

In the management of wild catch fisheries, regulating the commercial harvest of target species through the use of input and output controls has been a focal point. However, over recent decades there has been a growing emphasis on management approaches that consider the needs of all fishing sectors, and account for ecosystem-wide impacts. Some of the applied management outcomes that have come from future thinking include reducing incidental catches or impacts on non-target species through bycatch reduction technologies (Wakefield *et al.* 2017; Avery *et al.* 2017) and the future projection of environmental conditions to inform adaptive management boundaries (Hobday and Hartmann 2006; Hobday *et al.* 201[illegible]). Other areas of recent focus include broadening the scope of fisheries management to better achieve triple bottom-line outcomes (i.e. social, ecological and economic objectives) and recognising the issues that face all fishing interests (e.g. commercial, recreational, charter, conservation and traditional fishing) (Brownscombe *et al.* 2019; Dichmont *et al.* 2020). Underlying these complex challenges are the inherent complications associated with working at the political interface and how alternative arrangements such as non-regulatory, co-management frameworks and harvest strategies can be used to generate better outcomes (Nursey-Bray *et al.* 2018). Despite some recent progress in the management of fisheries or species, considerable work remains in order to progress the key science that informs direct management outcomes across the diversity of Australia's fishing landscape. The key research questions identified were:

1. How do we ensure adequate research funding from the state and Commonwealth to maintain sustainable fisheries?
2. How do we develop indices of recruitment and abundance to enable sustainable fisheries management in the face of increasing environmental change?
3. How can resource managers better prioritise species over politics?
4. How can we more effectively incorporate the effects of environmental variation in fisheries management?
5. How can state and federal agencies better adopt ecosystem-based fisheries management?
6. How should government agencies address gaps in basic biological information for key fish species?
7. How can recreational fisheries be managed for maximum environmental and socio-economic benefits?
8. How can fisheries management become adaptive under a changing climate?
9. How can we improve management of species of conservation interest in commercial fisheries?

10. How do we manage fisheries to reduce ecosystem impacts in a changing ocean?

Theme 5: monitoring and assessment

The effectiveness of fish and fisheries management is heavily reliant on the richness of available information (Carruthers *et al.* 2014). Given the difficulties of undertaking population surveys on aquatic fauna, it is critical that investment in monitoring and assessment aligns with efforts that will more accurately determine the status of a species or fishery. Traditional data collection in Australian fisheries has often focused on fishery-dependent sources (e.g. commercial fishing logbook data), with trends in catch rates used to inform changes in the abundance of species (Dichmont *et al.* 2021). In more complex assessments, these fisheries data are often complemented by biological information, and in some cases independent surveys on species of interest that are used to inform population models. This has also had a flow on effect of research projects more commonly being designed to focus on commercial wild catch fisheries, rather than data-limited recreational fisheries. The result of this is that research questions of highest importance to fisheries assessment may become lower priority due to their difficulty of implementation. To enhance the richness of data available to assess the health of fish populations within fisheries, monitoring of wild populations has expanded to survey additional forms of mortality (e.g. recreational fishing) or directly estimate biomass (Macaulay *et al.* 2018). Furthermore, there has been a growing emphasis on data collection and dissemination in near real-time. The key research questions identified to highlight the further challenges, data needs and concepts that are focal for progressing monitoring and assessment of fish and fisheries in Australia were:

1. How can recreational fishing harvest best be quantified?
2. How does the impact of recreational fishing on target species, compare to the impact of commercial fishing?
3. How can impacts of fishing on bycatch species be reduced?
4. How does recreational fishing affect fish population dynamics (e.g. size and age structure or post-release survival)?
5. How can we develop near real-time estimates of recreational fishing harvest?
6. How can we modify fishing gear to be more selective of target species and reduce bycatch?
7. What river systems contribute the most recruitment to commercial and recreational fisheries?
8. How do we cost effectively assess fish stocks where fishery-dependent data are no longer a reliable indicator of abundance?
9. What are the most effective fishery monitoring and validation methods for multi-species and small-scale fisheries?
10. How can the occurrence of illegal, unreported and unregulated fishing be identified and mitigated?

Theme 6: environment and climate

While implicitly linked with other major themes such as ecosystem and biodiversity, the impacts of climate change on aquatic ecosystems will include shifts in temperature, acidification, deoxygenation, changes in ocean currents and sea level rise. Given the increasing research dedicated to this field, it warrants its own thematic group. Inherently, changes to aquatic environments will significantly impact on fish and fisheries resources globally via influences not just at the ecosystem or habitat level, but also phenotypic changes that may occur as fish rapidly adapt to their new environment. Movement ecology is receiving particular attention as researchers rush to understand the rapidly depleting biodiversity in the tropics (e.g. the coral triangle) and how species distributions are tracking towards historically cooler regions at higher latitudes in line with their thermal affinity (Burrows *et al.* 2019). Flow-on effects on receiving ecosystems and their food webs remain unknown. Mendenhall *et al.* (2020) postulated that in addition to changes in fisheries productivity and distribution, human migration to and away from coastal areas, stresses on coastal fisheries infrastructure, and challenges to prevailing maritime boundaries will also ensue. As a result, an increase in fishery-driven disputes will occur, and thus new challenges for existing fisheries management institutions will emerge (Mendenhall *et al.* 2020). The key research questions identified under environment and climate were:

1. How will climate change impact on the movements of marine species?
2. How can we incorporate environmental variables into fisheries stock assessments to predict stock productivity and recovery?
3. Under a changing climate, which species will be vulnerable to extinction and which species will be able to move and establish in new habitats?
4. How best do we integrate environmental and fisheries data to scientifically demonstrate the effects of climate change on fisheries?
5. What will happen to fish population structures in relation to increased sea surface temperatures and marine heatwaves?
6. How will extreme events (e.g. marine heatwaves) impact fish populations?
7. How can spatial planning best incorporate the responses of fish and fisheries to environmental change?

8. Is climate change affecting the spawning habits and yield of our fish stocks?
9. How can climate change trend data be incorporated into planning and management to ensure effective long-term measures to protect ecological health?
10. How will climate change impact the survival of freshwater fishes?

Theme 7: emerging technologies, tools and approaches

Many of the key advances in our understanding of fish and fisheries have been driven by leaps in technology and methodology. The rapid development of molecular tools, remote sensing and wildlife tracking technologies over the past decade are several examples of where improving technologies have progressed our understanding of aquatic systems, their users and inhabitants (Lennox *et al.* 2017). For example, the transition from genetic approaches to genome-wide assays has allowed investigation of functional adaptation, stock structure, population size estimation and environmental DNA that can inform the current and future management of fishes and fisheries (Bravington *et al.* 2016; Kumar and Kocour 2017; Hansen *et al.* 2018). The use of remotely operated vehicles and drones represent technological advances, which allowed for low-cost visual fish surveys in otherwise inaccessible marine habitats (e.g. shallow mud flats or deep-water habitats) (Ventura *et al.* 20[illegible]; [illegible]alou *et al.* 2021). These emerging remote technologies are complemented by advances in mapping approaches and open access software (e.g. Google Earth), which have provided researchers with the ability to explore, analyse and communicate complex spatial data such as vessel movement or wildlife tracking (Campbell *et al.* 2012). The following key research questions are those that may be explored through the further enhancement, development or application of emerging technologies, tools and approaches:

1. How can we utilise technological advancements to enhance data collection in data-poor fisheries?
2. Can eDNA technologies be developed, validated and adopted as standard tools for detection of invasive, endemic or protected species?
3. How can scientists improve communication of their research to the general public?
4. Should regular genetic screening be conducted for early detection and monitoring of biosecurity threats at significant international shipping ports around Australia?
5. How can next-generation sequencing technologies be used to assess fisheries stock structure in a way that better informs fisheries management?
6. How can eDNA techniques be developed for use in semi-quantitative population level surveys of protected or threatened species?
7. What kind of cost-effective technology could be used to undertake surveys of fish species?
8. How can we better promote the development of new gene technology for control/eradication of introduced species?
9. How can we utilise emerging technologies for adaptive management?
10. How can genetic stock assessments be applied more widely in Australian fisheries?

Discussion

Contributions from stakeholders in academia, private, government, and non-governmental organisations in a horizon scan identified key research questions that are important to fish and fisheries in Australia. Through the stepwise approach we identified seven clear research themes to which questions aligned. The resulting top 10 questions for each theme were a culmination of the highest ranked original submissions and focused on creating research questions that would result in applied outcomes. This applied focus on question design makes the outcomes of this study suitable for consideration and adoption by management agencies or policy makers working in the Australia fish and fisheries community. These questions were intentionally designed to be broad in nature, while still retaining sufficient information content to ensure that projects can be designed to fulfil the intent of the question.

When observing the relationships among the priority questions across the themes, we found a number of expected and unexpected trends. For example, we found that for the 'ecosystem and biodiversity' and 'biosecurity' themes, priorities were more heavily related to freshwater systems. These are findings are not unexpected, and are likely to be associated with the greater threat posed by industrial development and biosecurity breaches in the freshwater environment, when compared to other threats such as fishing pressure (Kearney *et al.* 2019). It was also observed that themes directly related to 'fisheries' such as 'fisheries management' and 'assessment and monitoring', there was a greater focus on priorities to address questions related to the recreational sector than other sectors. This outcome is important as it highlights the need to better understand the effects of recreational fisheries on aquatic ecosystems (Holder *et al.* 2020), which differs from the traditional focus of fisheries research on data or activities associated with wild catch commercial fisheries (McPhee *et al.* 2002).

We expect that these research priorities will be built upon to support existing research and development initiatives, identify new and important areas of research, encourage opportunities for collaboration, and improve certainty around decision making. The advantage of this horizon scan is that it does not seek to achieve objectives of a specific organisation, but rather provides a bottom-up approach that is independent of a participant's employment. As a result, the questions represent personal opinions rather than the strategic direction of an agency or organisation. We foresee the outcomes of this research will be of direct use to researchers and panel members involved in competitive grants programs that do not list dedicated research priorities such as the Australian Research Council's National Programs. Moreover, the priority research questions identified herein are developed at the operational level, which allows methods to be designed to address them. This is in contrast the strategies, challenges, visions and outcomes outlined in existing strategic initiatives such as the National Marine Science Plan, which are often described at a higher level to ensure that they align with international objectives such as the United Nations Sustainable Development Goals (NMSC 2015). As a result, the operational level priorities of our work should directly complement these plans and provides a resource where funding organisations can look to when targeting future investments around high priority areas in fish and fisheries.

The priorities are also complementary to the Fisheries Research and Development Corporation (FRDC) research priority setting process, and their Research and Development Plan 2020–2025 (FRDC 2020). FRDC Research priority setting is guided by stakeholder involved Research Advisory Committees. Fishery stakeholders such as commercial or recreational fishers often have good knowledge on their region or fishery of interest, but may not be aware of the broader importance of related issues also relevant to them. It is hoped that this list of priorities will greatly assist stakeholders on Research Advisory Committees to understand whether the research needs of their fishery or sector may be of broader national interest. The complementary nature of this work and that of FRDC is also emphasised through many of our research themes that directly align with the planned outcomes from the R&D plan. For example, questions from the theme 'resource management and stewardship' align with 'Outcome 5: Community trust, respect and value' (FRDC 2020). The inclusion of resource user and stakeholders in future horizon scanning work could further tighten the linkages between these two approaches.

We attempted to reach as broad an audience as possible as part of this work, but we recognise that the survey reach was restricted to the dissemination of survey hosts, participants and to lists of committees, which is a limitation of the work. We foresee that future horizon scans may be able to access a broader network and reach members of other groups of stakeholders of whom we are currently unaware. While this will be an important next step, we are the first to undertake such an exercise and feel that we have provided a useful framework on which to build.

Conclusion

Our horizon scan identified key questions for progressing fish and fisheries throughout Australia. These knowledge gaps allow researchers to seek investment and target their skills around issues that are important for the future of our species, ecosystems and fisheries. It is hoped that future horizon scan activities are undertaken to allow for continual development and reflection in the issues that face research, academics, stakeholders and managers working in the field.

Supplementary material

Supplementary material is available online.

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