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The importance of research and public opinion to conservation management of sharks and rays: a synthesis

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Abstract. Growing concern for the world's shark and ray populations is driving the need for greater research to inform conservation management. A change in public perception, from one that we need to protect humans from sharks to one where we must protect sharks from humans, has added to calls for better management. The present paper examines the growing need for research for conservation management of sharks and rays by synthesising information presented in this Special Issue from the 2010 Sharks International Conference and by identifying future research needs, including topics such as taxonomy, life history, population status, spatial ecology, environmental effects, ecosystem role and human impacts. However, this biological and ecological research agenda will not be sufficient to fully secure conservation management. There is also a need for research to inform social and economic sustainability. Effective conservation management will be achieved by setting clear priorities for research with the aid of stakeholders, implementing well designed research projects, building the capacity for research, and clearly communicating the results to stakeholders. If this can be achieved, it will assure a future for this iconic group, the ecosystems in which they occur and the human communities that rely on them.

Additional keywords: chondrichthyes, research priorities, sustainable use.

Introduction

Shark and ray populations in many parts of the world's oceans are in decline. These include coastal (Shepherd and Myers 2005; Dudley and Simpfendorfer 2006), open-ocean (Dulvy *et al*. 2008), deep-sea (Simpfendorfer and Kyne 2009; Kyne and Simpfendorfer 2010), estuarine (Simpfendorfer 2000) and freshwater (Thorson 1982; Compagno and Cook 1995) populations. These populations face a variety of threats, most notably from fishing (Bonfil 1994), habitat degradation (Jennings *et al*. 2008), pollution (Gelsleichter *et al*. 2005) and climate change (Chin *et al*. 2010). These declines are exacerbated by their life history – slow growth, late maturity and small numbers of young relative to most other aquatic taxa (Musick 1999) – and as a result, populations have less potential to sustain fishing or to recover from depletion than do most teleost fish or invertebrates (Simpfendorfer 2000). Although no species of shark or ray are known to have become extinct in the wild, several species have been extirpated from large parts of their range (Dulvy and Forrest 2009), and 67 species are currently listed as Critically Endangered or Endangered on the IUCN Red List (www.iucnredlist.org, accessed 20 April 2011). Despite the well documented serious declines in some species, many others have not declined, or have not declined to unsustainable levels, with 373 species on the IUCN Red List being listed as Least Concern or Near Threatened.

The loss of some shark and ray populations from aquatic ecosystems has socioeconomic and ecological consequences. First, sharks provide a source of protein, as well as a variety of other products (e.g. leather, fins, cartilage, liver oil) that are important to communities in both developing and developed nations (Bonfil 1994). Whereas some fished populations are managed within sustainable limits (e.g. gummy shark, *Mustelus antarcticus*, in southern Australia; Walker 1998), most are fished without knowledge of their sustainability or at levels above scientifically recommended limits (e.g. Fordham 2009; Pawson *et al*. 2009). The lack of sustainable fishing practices for shark and ray populations will mean that this source of protein will need to be replaced by other sources, most of which are already at or above sustainable limits, or consumption will need to decline. Second, the decline of shark and ray populations has ecosystem consequences (Stevens *et al*. 2000). The role of some shark species as top predators exerts top-down effects on

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ecosystems (Carlson 2007), and their loss or decline may have important direct and indirect effects on populations (Heithaus *et al*. 2008; Polovina *et al*. 2009) that can cascade through marine ecosystems (Baum and Worm 2009). The loss of sharks may result in substantial changes to ecosystems that affect other organisms and the industries and human communities that rely on them.

Given the socioeconomic and ecological consequences of declining shark and ray populations, there is an imperative to address declines by implementing effective conservation management. This action will need to be underpinned by sound social, economic and ecological research. The current special issue contains 23 papers from a wide range of research fields, many of the findings being relevant to conservation management. However, research on sharks is rarely considered in a framework of the needs for the development of conservation actions, although it is often stated that there will be benefits from the work. Here, we synthesise the research that will contribute to effective conservation management of shark and ray populations, and examine how a change in the public perception of sharks has affected the imperative for this action.

The effects of a changing perception of sharks

For centuries, sharks were feared because of occasional attacks on humans who enter their aquatic world. In 2010, there were fewer than 80 attacks and only six fatalities caused by a handful of species (Burgess 2011), yet shark attacks can have severe consequences for both the victims and the tourism industry (Cliff 1991). The fear of shark attack resulted in an early wave of research that aimed to protect humans from sharks, focusing on sensory biology (Gilbert 1963; Hodgson and Mathewson 1978), behaviour (Johnson and Nelson 1973; Nelson 1977) and attack prevention (Gilbert 1963). Despite extensive research, few solutions were found to protect people; however, much was learnt of the sophisticated sensory and behavioural biology of sharks.

One approach that did gain favour was shark-control programs to reduce the numbers of dangerous sharks near popular swimming beaches (Cliff and Dudley 1992). Programs were instituted in Australia, South Africa, Hawaii, New Zealand and Hong Kong and have proven successful, with few attacks at protected beaches (Dudley 1997). However, these public safety programs also come at an environmental cost of elevated mortality, not just of sharks, but also other species (turtles, dolphins, dugongs, rays and fishes). This collateral environmental damage has resulted in the removal of some programs (Wetherbee *et al*. 1994) and others have made changes to minimise these environmental effects while maintaining public safety (Cliff and Dudley 2011). In addition to their perceived public-safety benefits, shark-control programs have also been an invaluable source of information on shark and ray life histories (e.g. Simpfendorfer 1992), status (e.g. Dudley and Simpfendorfer 2006) and ecology (Taylor *et al*. 2011). Reid *et al*. (2011) reported on decadal trends in species caught by the New South Wales shark-control program, providing a long time series of data on the abundance of large sharks in this region. Such data not only help inform how individual populations have changed over time, but also how the community structure of netted sharks has changed. These types of data will underpin conservation management by providing the evidence about which species need to be recovered, and by how much.

The lack of science-based solutions to eliminate the risk of shark attacks on humans has not stopped people using the ocean. In fact, West (2011) reported that, at least in Australian waters, ocean use has increased dramatically, and as a result the incidence of attacks, relative to total population, has increased over the past 20 years. This suggests that the fear that society once had for sharks has decreased, and with it has come a change in attitude towards sharks.

The changing societal perception of sharks has played an important role not only in use of the ocean, but also in relation to research, management and conservation. This change in perception has occurred over a period of several decades. Whatmough *et al*. (2011) examined the change in the perception of sharks among divers from the 1950s to today and documented the shift from ‘adventure-seeking hunters’ focussed on spear-fishing sharks towards ‘nature-seeking observers’. This alteration echoes wider societal changes in attitudes towards conserving marine biodiversity over the consumption or taming of natural resources. Today, with the change in perception, from one of needing to protect humans from sharks, to that of needing to protect sharks from humans, there is widespread acknowledgement of the need for conservation and management.

The reasons for this change in perception are poorly understood, but no doubt have been contributed to by a better understanding of sharks and the oceans. This is largely thanks to the work of scientists who have provided evidence of the sophisticated nature of sharks (Clark 1969), their importance in ocean ecosystems (Stevens *et al*. 2000) and the effect that humans have had on many populations (Dulvy *et al*. 2008). This change in perceptions of sharks and rays has led to a shift in value from direct consumptive values towards indirect values of the existence of species and willingness to bequest and guarantee the future of sharks for future generations. The recognition that sharks can also provide financial benefits to communities beyond those provided by fishing has contributed to the perception of the value of sustaining the world’s sharks. For example, Clua *et al*. (2011) demonstrated that the tourism value of lemon sharks (*Negaprion acutidens*) could provide significant ongoing financial benefits to communities on Pacific islands over and above the one-off payment for catching and killing the sharks.

The change in perception of sharks has had several significant implications for scientific research. First, there has been an increase in the resources available to support research, and as a result, there has been a dramatic increase in the amount of research conducted over the past 40 years. This is evidenced by a seven-fold increase in citations in Web of Science on the topic ‘shark’ (excluding ‘Shark Bay’), from 383 (1972–1981) to 2711 (2002–2011) (Web of Science search, 3 March 2011). The increase in research has also been supported by an increase in people willing to undertake this research, especially at the student level. This is demonstrated by the importance of students within professional societies dedicated to the study of sharks and rays (e.g. 38% of Oceania Chondrichthyan Society members were students at the beginning of 2011) and also the growth in the number of societies dedicated to the science, conservation and management of chondrichthyans – European Elasmobranch Society, and Oceania Chondrichthyan Society, to name but two.

The change in perception of sharks has also had some negative effects on research. Heupel and Simpfendorfer (2010) documented how the increased conservation ethic has limited some types of research (e.g. lethal life-history studies) that can actually improve conservation outcomes. Given that 44% of shark and ray species are listed as Data Deficient on the IUCN Red List, such basic research will be required to ensure ongoing improvement in science-based conservation outcomes.

The role of science in conservation management of sharks

Given the knowledge that some of the world's shark and ray populations are in decline, that some have a high potential risk of extinction in the future (Garcia *et al*. 2008), and that almost half have insufficient data to support any form of assessment (Heupel and Simpfendorfer 2010), there is a strong ongoing need for science to help improve the conservation management of this group. These research needs fall into a broad range of topics (Table 1), including work to understand and describe their biodiversity, basic biology and life history, the ecology of populations, their role in ecosystems, and the effects of changing environments. Alone, however, these traditional research topics will be insufficient to fully implement conservation because managing resources is as much about understanding the resource as it is about managing the people who exploit it (Hilborn 2007). Thus, research to understand the values, behaviours, attitudes and actions of the people, industries and communities that depend on sharks and rays will be equally as important. This is an area of research that has lagged well behind that of the biology and ecology of the group.

Biological dimensions

Taxonomy is the foundation of all other biological sciences; without a valid species name, research is difficult to place into context. The sharks and rays are a diverse group, with in excess of 1100 species currently known (Last and Stevens 2009) and increasingly more being described. Despite their relatively large size, new species continue to be located and described, often in locations where fishing is intense and often in some of the best-studied ecosystems in the world (White and Kyne 2010). Taxonomic research to understand the full biodiversity of the group will be important so that managers know the range of species for which conservation measures need to be implemented, as well as for researchers to be able to identify their research subjects. There is often a common misconception that the taxonomy of sharks and rays has been completely resolved. In fact, in the past 5 years, 145 new chondrichthyan species have been described, which represents ~13% of the global shark and ray biodiversity.

Taxonomic research provides essential information required for most other research areas and, if not fully resolved, can lead to problems in the future. For example, Iglésias *et al*. (2010) revealed that catches of the Critically Endangered flapper skate (*Dipturus batis*) are a species complex, and in the north-eastern Atlantic, the catches actually belong to two different species. This puts into question all the previous data on this species and also reveals that the risk of extinction of the two species involved is likely to be much higher than was considered for *D. batis*. Another example is the realisation that the North Pacific population of spiny dogfish is actually a distinct species, the spotted spiny dogfish (*Squalus suckleyi*) (Ebert *et al*. 2010). These recent discoveries of new species that are already heavily exploited serve to remind us that good taxonomy underpins conservation and management (Dulvy and Reynolds 2009). Research is also needed on those species that are known from very few specimens, and are currently considered to have a very high risk of extinction. For example, Moore *et al*. (2011) redescribed the poorly known smoothtooth blacktip shark (*Carcharhinus leiodon*) and provided a much clearer understanding of its distribution, biology, status and susceptibility to fisheries. Nowhere is this type of research more needed than in the deep sea (Kyne and Simpfendorfer 2010), from where the majority of new species are being described (Last and Stevens 2009). Without this type of research, we are at risk of losing species before we even know they exist.

The setting of sustainable limits for sharks and rays under conservation management plans will rely on having accurate life-history data, or, at the very least, acknowledging the limitations and uncertainty of the available data and models (Walker 1998). Life-history data inform decision-support tools such as ecological risk assessments (Braccini *et al*. 2006), demographic models (Cailliet 1992), stock assessments (Walker 1992) and ecosystem models (Stevens *et al*. 2000) that are widely used to set catch limits for many fisheries or species. Wiegand *et al*. (2011) examined the sensitivity of their demographic model to the potential range of uncertainty in the input life-history parameters. Another source of uncertainty comes from the underlying assumptions of many demography methods; the pragmatic choice of one or other may profoundly affect the outcome (Braccini *et al*. 2011). This suggests that although pragmatism may be necessary in a data-limited situation, we should always ensure that assumption testing is on the research agenda.

Despite the importance of life-history parameter estimation research, proportionally fewer studies are conducted today than even a few years ago. This is evidenced by the fact that 38% of the papers published from 'Sharks Down Under Conference' in 1991 (Pepperell 1992) were related to life history, whereas life history-related papers account for only 24% of those published in the current conference volume. The types of research that are needed include reproductive biology (Ainsley *et al*. 2011; Graham and Daley 2011; Mull *et al*. 2011), age and growth (Tanaka 2011) and mortality (Simpfendorfer *et al*. 2005). In particular, research targeted at endangered species (e.g. Kyne *et al*. 2011) will provide significant benefits to conservation management because it provides data on species with the most critical needs. Comparative life-history data are available for only 4 of the 10 orders (Carcharhiniformes, Lamniformes, Squaliformes and Rajiformes). Even then, data are patchily distributed across a few select species and genera (Frisk *et al*. 2001). It will be important that life-history research continues to be supported and pursued, despite the fact that it often requires lethal sampling to occur (Heupel and Simpfendorfer 2010).

The spatial ecology of elasmobranchs is one new growth area in research, driven largely by the rapid miniaturisation and increasing sophistication of tags and tracking arrays. Many of the key questions in the spatial ecology of elasmobranchs are highly relevant to conservation management. Our understanding of the broader spatial scale of movement as well as the details of fine-scale habitat use has revealed considerable

Table 1. Research needs for the development of effective conservation management of sharks and rays

Topic	Research needs	Research questions	Outcomes for conservation management
Taxonomy	Description of new species	How many species are there? What are the rates of evolution?	Identifies scope of conservation management and associated research
	Relationships between species	What are the speciation patterns? What are the evolutionary relationships within the group?	
	Production of identification guides	How can taxonomic capacity be increased?	
Life history	Reproductive biology	How many young are produced and how often? How does reproductive rate change with age? What is the gestation period? At what age and size do they mature? What is the size of the newborns? What are the mating systems? What are the reproductive modes?	Basis for designing management strategies and setting sustainable limits
	Age and growth	How old do they grow? How fast do they grow and how does this change with age? What are the best methods to determine age and growth? How can age estimates be validated?	
	Mortality estimation	What are the natural mortality rates? Does natural mortality vary by sex, age or habitat? How can natural mortality be accurately determined?	
	Population dynamics	How do life-history parameters change with population density? (i.e. what are their compensation mechanisms?) How can life history be studied using non-lethal techniques? What are the general life-history patterns within the group?	
Spatial ecology	Stock structure	What is the distribution of species? What is the scale of substructuring in populations? What factors give rise to stock structuring?	Design and evaluation of spatiotemporal management; appropriate scales of conservation management actions
	Movement and migration	What is the connectivity of populations? Where do they move to and when? How much space do they use by age and sex? What are their migratory pathways? Are they philopatric and to what areas? What are their movements in relation to MPAs? What are the best ways to model movement? How can movement data be incorporated into assessments? Do human activities change movement patterns?	
	Habitat use and preference	How long do they remain resident within a given habitat? What are the habitat-use patterns by age and sex? What factors affect habitat choice? What habitats contribute most to population growth? What locations are important for mating or pupping? How do we account for individual variation within a species?	
Environmental effects (incl. climate change)	Environmental effects on life history, behaviour and spatial ecology Effects of rising sea temperatures Effects of ocean acidification	How do changing environmental conditions affect life history, behaviour, and spatial ecology? What are the effects of pollution? How will climate change and ocean acidification affect sharks and rays?	Adaptation strategies for species, ecosystems, industries, communities and conservation management plans

(*Continued*)

Table 1. (Continued)

Topic	Research needs	Research questions	Outcomes for conservation management
Ecosystem role	Diet and trophic structure	What is their diet and how does this change with ontogeny? What are the best methods to examine diet and trophic linkages? What roles do sharks and rays play in aquatic ecosystems?	Application to ecosystem-based management
	Ecosystems response to sharks removal	What happens to ecosystems when sharks or rays populations are reduced?	
	Ecosystem models	What are the best modelling approaches to examine ecosystem effects? Can we predict the effects of shark or rays on ecosystem function? What are the best decision-support tools for ecosystem-based management?	
Fishery status	Catch and effort	What is the catch and value of sharks in fisheries? How much effort is expended in fisheries that catch sharks or rays? What is the extent of fisheries? Is there full reporting of catches? What products are utilised and how are they traded? How effective are observer programs? What are the cumulative impacts of multiple fisheries?	Identify threats to populations
	Species, sex and size composition	What is the catch by species, sex and size? What is targeted, by-product and by-catch? How do catch and effort change in space and time?	
	Gear selectivity	What is the selectivity of the gears used?	
Population status	Ecological risk assessments Demographic models Stock assessments Management-strategy evaluation	What is the status of populations? What are the best methods to determine status? How should models be selected? What are the sustainable limits of populations? What management strategies produce the best outcomes? How can cumulative impacts be assessed? How can assessments be carried out in data-limited situations? How is uncertainty best incorporated into assessments? How is uncertainty about parameters and model structure best communicated to end-users? Can we predict the species most at risk of decline?	Identification of at-risk species; decision-support tools for resource managers to help set sustainability limits
Human dimensions	Human values, attitudes, beliefs and behaviours	What are the attitudes of different segments of society to sharks and rays? How can these attitudes be used to best implement conservation management? How do values, attitudes and beliefs affect the way people interact with sharks and rays? What is the existence value of sharks and rays? What is the best way to communicate with stakeholders?	Design of conservation management plans that take account of human behaviour, optimise economic outcomes for people, industries and communities
	Economic value of sharks to both extractive and non-extractive uses	What is the economic value of sharks? Is non-extractive value > extractive value? What is the value of recreational shark fishing? How can value be maximised?	
	Governance models	What are the appropriate governance structures? How can international approaches be coordinated?	

surprises over the past decade, such as ocean-crossing transits in white shark (Bonfil *et al*. 2005), hurricane-detection in juvenile blacktip sharks (Heupel *et al*. 2003) and selective tidal transport in the thornback ray (Hunter *et al*. 2005). Understanding spatial ecology is essential for understanding the risks faced by endangered species or the effectiveness of habitat restoration. This research includes the investigation of migrations and long-range movement using satellite-based telemetry. For example, Otway and Ellis (2011) used pop-up satellite archival tags to investigate the movements in the populations of Critically Endangered grey nurse sharks (*Carcharias taurus*) on Australia's eastern coast. Acoustic telemetry has been used to study finer-scale spatial ecology of sharks and rays. Farrugia *et al*. (2011) used acoustic telemetry to track the movements of the shovelnose guitarfish (*Rhinobatos productus*) within a restored estuarine habitat to study its fine-scale habitat-use patterns. The ease of use and broad appeal of telemetry approaches is likely to ensure that this field of research continues to expand rapidly.

Spatial ecology research, however, is not only based on new and improving telemetry technology, but there has also been a growth in the use of photo-identification to document individuals at aggregation sites and infer movements. Couturier *et al*. (2011) have used photo-identification to study the movements of manta rays (*Manta alfredi*) along the Australian eastern coast, providing the first understanding of the movements of this iconic species in this region. Similarly, Rowat *et al*. (2011) used photo-identification to examine the residency of juvenile whale sharks (*Rhincodon typus*). More traditional approaches to studying space and habitat use by sharks and rays are also still utilised. For example, Taylor *et al*. (2011) investigated the spatial partitioning of large sharks and rays by using catch data from the Queensland Shark Control Program.

No matter which techniques are used to investigate the spatial ecology of sharks and rays, the data that this type of research yields will play an important part in improving conservation management. Understanding the long-distance movements and migrations can provide information on the appropriate scales at which to apply management. Fine-scale data are used to identify habitats or locations that are important to a species of concern and should be considered for protection (Simpfendorfer *et al*. 2010). Movement data are also essential for the design and evaluation of spatial management approaches, most notably Marine Protected Areas (Grüss *et al*. 2011). Research that identifies areas (e.g. nursery or mating areas), times (e.g. pupping seasons) or habitats (e.g. estuaries close to human settlements) in which species are more vulnerable to human impacts will contribute significantly to the development of spatial management approaches. Despite the growth in the use of spatial management in the ocean, the mobile nature of many sharks and rays means that marine protected areas (MPAs) may not always be the best approach to conservation management. A comparison of the potential effectiveness of seasonal closures and size limits for halting declines of thornback rays (*Raja clavata*) suggests that although MPAs might lead to more rapid recovery, the use of size limits would better suit the management systems and minimise conflict with trawl fleets targeting other species (Wiegand *et al*. 2011). Such approaches are helping managers and policy makers design the best possible conservation management plans.

One research field that is relatively mature is that which explores how human activities interact with shark and ray populations. This can be seen in the abundance of information on the species and size composition of sharks and rays in fisheries. For example, Harry *et al*. (2011) described the shark and ray catch of the gill-net fishery that operates along the eastern coast of Queensland. These types of data are important because they identify the species that conservation management needs to consider, and can help determine priority species. Human activities can also have delayed or sublethal effects, and research to develop and evaluate tools that enhance the ability to identify them can provide useful data. For example, Awruch *et al*. (2011) validated a cheap portable field kit for determining lactate concentrations in sharks, a method that will allow researchers to quickly and easily determine the level of stress of sharks in a variety of conditions. Human effects do not always come from fisheries, but can still have significant implications. For example, tourist operators often deploy baits to attract sharks to dive sites, with largely unknown consequences. Clarke *et al*. (2011) explored how the deployment of baits affected the residency of silky sharks (*Carcharhinus falciformis*) at Red Sea reefs to help understand the implications of this practice. This type of research will help inform the development of management plans for tourism operations and other non- extractive uses.

Research that investigates the status of species will be vital to conservation management because it identifies those species that are at risk and helps set recovery targets. The approaches used in the assessment of a species status can have important implications for the results, and it is imperative that research on the status of species uses appropriate methods and all of the available data. For example, the effects of subjective judgement in assessing the status of a species was explored by Braccini *et al*. (2011) who demonstrated significant differences in outcomes depending on the assumptions used. The validation of assumptions and data are therefore important in research on the status of species, and in providing confidence in the outcomes of analyses. Long time-series of data can also increase the certainty about the status of species because it avoids concerns about what occurred before the collection of data (Pauly 1995). Unfortunately, for sharks with long life spans, there are few datasets that meet these criteria. One source of long-term data is a shark-control program (Dudley and Simpfendorfer 2006).

For many years, there has been recognition that sharks are likely to play an important role in the functioning of ecosystems (Stevens *et al*. 2000), and that this is one important reason for the development of conservation management. There are good data on how sharks interact with an ecosystem through diet studies (Cortés 1999), and now more recently, stable-isotope studies (e.g. Papastamatiou *et al*. 2010). However, there has been very limited empirical analysis of what happens (both directly and indirectly) when sharks or rays are excluded or reduced in an ecosystem (Heithaus *et al*. 2008). Research that does this across the spectrum of species and the ecosystems in which they occur will be a major driver in refining our understanding of this important topic, and aid in developing conservation management that takes account not just of individual species, but the whole ecosystem where they live. This ecosystem-based management approach has become very popular in concept (Lester *et al*. 2010); however, it is at present poorly supported

by reliable decision-support tools that enable researchers and resource managers to explore policy options.

In addition to the widespread problems of fishing impacts, there is increasing concern about the direct and indirect impact of climate change on coastal sharks and rays. How populations will respond to climate change is a major concern and an area of research that is lagging behind that for other taxa. Some vulnerability risk assessments are available (e.g. Chin *et al*. 2010); however, there is little detailed understanding of the pathways by which climate change will affect elasmobranchs. Altered precipitation is likely to heavily influence freshwater flows and inputs into the coastal zone, with consequences for the distribution of river- and estuarine-associated sharks and rays. More research is currently being carried out that examines how sharks and rays respond to short-term environmental changes. For example, Knip *et al*. (2011) reported how juvenile pigeye sharks (*Carcharhinus amboinensis*) move from their normal near-shore distribution near river mouths to areas further offshore during periods of high freshwater flow. Understanding the linkages among climate change and terrestrial land-use change and coastal sharks and rays can aid in the development of catchment management plans (Heupel and Simpfendorfer 2008; Simpfendorfer *et al*. 2011). Ultimately, research that improves our understanding of short-term responses to changing environmental conditions will also aid in understanding how sharks and rays will respond to longer-term changes in their environment.

Human dimensions

As identified above, research on the human dimensions of sharks, the industries that exploit them and the human communities that depend on them will be critical for the success of conservation management. This type of research includes consideration of the economic value of resources, both from an extractive fisheries perspective (Campbell *et al*. 1992) as well as from the non-extractive uses (Clua *et al*. 2011). Such research will help inform the best way to maximise economic yields, while still ensuring resource sustainability. For some species, there is high economic value in maintaining populations that can be viewed by tourists (Stoeckl *et al*. 2010); however, this will not be true for all species (i.e. those that non-extractive use cannot access). The benefits that industries and communities derive from the use of shark and ray populations will potentially change into the future under scenarios of change (e.g. climate change, shifting markets). Research that investigates the ability of these industries and communities to adapt to changing conditions will enhance their sustainability, just as similar ecological research can help enhance the sustainability of the shark and ray populations.

Whereas economics is a key driver of decision-making by humans (and hence how they approach resource use), values and attitudes can also be important factors. Understanding these factors will improve the implementation of conservation management. For example, Lynch *et al*. (2010) demonstrated that within the waters of the Great Barrier Reef (GBR), the attitudes of recreational fishers towards sharks were mostly positive, underpinning a very high rate of release of sharks in good condition. Lynch's research demonstrated that if attitudes were to change, the release rates would decline and the effect of recreational fishing on sharks populations of the GBR would increase. Similarly, research that charts the change in human attitudes over time (e.g. Whatmough *et al*. 2011) provides a measure of how supportive the public may be of conservation management.

With many species having broad distributions or undertaking large migrations, governance structures that incorporate cross-jurisdictional approaches will be essential (Techera and Klein 2011). Research that identifies governance models that optimise the benefits of conservation management will provide for more efficient implementation and enhance the chances of success. Governance structures that incorporate both extractive use and non-extractive use will also be useful in developing conservation management.

Priority setting and communication

The diversity of the sharks and rays, and the variety of habitats in which they occur, means that there is an enormous amount of research to do to help inform conservation management and a limited scientific capacity. It is unrealistic to think that anything more than a small fraction of the research that is required to develop comprehensive conservation management for all shark species will become available over the next decade. Thus, it will be important to prioritise this research on those aspects that are seen as most important. For conservation management, this may be species identified as being at risk (e.g. all seven species of sawfish, family Pristidae, are listed as Critically Endangered on the IUCN Red List), habitats that are at risk (e.g. coral reefs under threat from climate change, Chin *et al*. 2010) or industries that pose the greatest risks (e.g. deep-sea trawling, Kyne and Simpfendorfer 2010). At present, a small number of high-profile species (e.g. white shark, whale shark and manta rays) attract a disproportionate amount of the attention of researchers (especially the younger generation) and research funding. If the conservation-management needs for all shark and rays species are to be met, then this imbalance will need to be addressed. At a global scale, there is limited coordination and priority setting for the research that will underpin shark and ray conservation management. For example, nations that develop National Plans of Action under the United Nations Food and Agricultural Organisation's International Plan of Action (Techera and Klein 2011) undertake some level of priority setting. Priority setting can also happen at lower levels, such as at local management levels or at an industry level (e.g. within specific fisheries). The attainment of research goals will also depend on the availability of qualified researchers who can provide the results. As such, continued training and capacity building will be important for the ongoing development of conservation management. The lack of global coordination for the conservation management of sharks and rays has led to calls for the creation of an agency similar to the International Whaling Commission (Herndon *et al*. 2010).

There is also a need for the clear communication of the results of research to those responsible for conservation management, including other scientists, managers, policy makers, conservation groups, industry groups and the public. At present, the responsibility for this communication rests mostly with individual researchers and to some extent with research funders. The development of repositories to help store and distribute both data and the results of research would be useful in improving communication, reducing the amount of time spent looking for suitable information to develop conservation management and enhancing research coordination. Without clear communication

of results, conservation management will be less efficient and the recovery of populations will be slowed.

In addition to the applied research that dominates shark and ray studies, there is also a wide range of fundamental science revealing new dimensions and understanding of the diversity and complexity of the group. One of the most unique features of elasmobranchs is their sixth sense – electroreception. Little is known of how sharks detect small-scale variation in electric currents present in their environment. Marzullo *et al*. (2011) showed that an oligohaline stingray has an electroreception system that has elements comparable to both freshwater and marine relatives. Another key mystery is the evolution of live-bearing in chondrichthyans, more than half of which give birth to live young compared with a fraction of a per cent in teleosts. Ellis and Otway (2011) unveiled new details of the environment in which the embryos of wobbegong sharks develop. Mull *et al*. (2011) revealed one possible advantage of investing in live young – matrotrophic sharks have brains that are 20–70% larger than those of similar-sized leicithotrophic species. These types of discoveries are important because they can have other societal benefits, including development of new materials, biomedical discoveries, understanding of other biological processes, and can also help change the public's understanding of sharks (and hence their receptiveness to conservation management that may affect them).

Conclusions

The alarming decline in some populations of sharks and rays generates a growing need for conservation management for many species in this group. The changing public perception of sharks and rays has increased awareness of the risks faced by this group, and added to the calls for action to address declines where they have occurred. There are research needs across a wide spectrum of fields to provide the science that will underpin sound approaches to conservation management. These include a range of biological and societal aspects that will inform not only about the biological sustainability of the group, but also about the social and economic sustainability of industries and communities that rely on them. Without this research, conservation management will be severely hampered and a precautionary approach will be required. By setting clear priorities for research, implementing well designed research projects and effectively communicating the results to stakeholders, more effective conservation management will be developed, assuring a future for this iconic group, the ecosystems in which they occur and the human communities that rely on them.

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