CSIRO PUBLISHING
Lead Essay
www.publish.csiro.au/journals/mfr
Marine and Freshwater Research 2007, **58**, 1–3

The state of research on chondrichthyan fishes

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More than a decade has passed since the Convention for Trade in Endangered Species (CITES) first alerted the United Nations Food and Agriculture Organization (FAO) of the urgent need to establish programs for collecting biological and trade data and for managing the impacts of fishing on shark populations. By 2000, FAO had developed the International Plan of Action for the Conservation and Management of Sharks (IPOA-Sharks) to form part of the Code of Conduct for Responsible Fisheries. Under the IPOA-Sharks, each of more than 80 signatory nations is obliged to develop and implement a National Plan of Action for the Conservation and Management of Sharks, where the term 'shark' covers all chondrichthyan groups (sharks, batoids, and holocephalans) (Anon. 2000).

The IPOA-Sharks emphasises that the harvest of chondrichthyan fishes should be biologically sustainable, economically rational, utilising all body parts of the sharks killed, and managed to ensure biodiversity conservation and maintenance of ecosystem structure and function. However, despite the best intentions for better management by many nations, fishing for these species continues to increase in response to the ever-growing demand for shark meat and other products from these animals. Shark fins, for example, are among the most highly priced fisheries products in eastern Asia and this is stimulating the targeting of sharks and retention of only their fins, the practice known as 'finning'.

Direct fishing mortality is not the only impact on chondrichthyan populations. There are fishing impacts on habitats through disturbance of biotic communities and substrates. Shipping and underwater exploration, construction, mining, and electrical installation also affect habitats, and increasing ambient sound, light, electromagnetic fields, and chemical contamination stimulate the sensory systems of chondrichthyan fishes. Understanding and measuring responses to these impacts and others such as from invasive species and perhaps aquaculture pose enormous research challenges. An overlay to complicate the research difficulties addressing these impacts is the uncertain magnitude of climate change, the effects of which have the potential to obscure the effects of fishing and other anthropogenic activities.

Research will have to be an important component of developing appropriate management responses to address many of these impacts. Innovative approaches are required for collecting more-comprehensive datasets, and for managing, securing, disseminating and analysing data. Promising developments at present are in the fields of enhanced computing capacity and electronic miniaturisation coupled with improved battery technology, remote and underwater sensing, and automatic data logging.

Advances in modelling methods during the past 20 years have followed growing computing capacity, which has led to the widespread use of numerical methods for fitting models to large datasets. In risk assessment frameworks to embrace uncertainty, this has enabled the application of complex fishery models tailored to specific fisheries and to the peculiarities of the biology of the species harvested. Despite these advances and the urgent need, the number of assessments of chondrichthyan fish stocks integrating time-series indices of abundance, the history of extracted catches, selectivity of the fishing gear, and their biological peculiarities using age- or length-structured models and allowing for density-dependent responses to changing population size in response to fishing, can be counted on one hand (Punt and Walker 1998; Punt *et al*. 2000; Pribac *et al*. 2005). Current assessments are mostly based on fishery-dependent data such as catch per unit effort for provision of abundance indices, but could be improved by greater use of fishery-independent survey data. Presently, there are insufficient funds, expertise, and time for collecting the data required to undertake such assessment of more than a tiny fraction of impacted species; clearly, in addition to these methods, more strategic approaches to research and management involving simpler and less data-intensive methods are required.

Systems approaches are required to investigate the validity of implicit assumptions such as stock-recruitment relationships holding constant over time underlying most single-species and multi-species stock assessments. Assumptions that ecosystems can maintain stability in response to on-going harvest and random oceanographic events, and can recover to earlier states following reduced harvest, have not been adequately tested. The effects of the removal of a significant proportion of the biomass of one species on the dynamics of another species, a fish community, or ecosystem need to be better understood; particularly for chondrichthyan species given their comparatively low biological productivity and, for many species, their trophic positions at or near the top of the food web.

10.1071/MF06223 1323-1650/07/010001

While there is an ongoing need for monitoring and assessment, rapid assessment techniques are required to identify species at high risk and in need of special management or protection. One such approach—referred to as 'ecological risk assessment from effects of fishing'—is emerging in Australia. Part of this approach involves assigning each species to risk categories based on 'biological productivity' and 'catch susceptibility' derived from biological attributes and expert judgment (Stobutzki *et al.* 2002; Walker 2005). Examples of attributes used include longevity, fecundity, size or age at maternity, species distribution relative to fishing areas, and position in water column in relation to the fishing gear (Braccini *et al.* 2006). Any ancillary information, such as trends in abundance, location of critical habitats, and habitat degradation, needs to be incorporated into the approach. In accordance with the precautionary principle, the absence of information is treated as high risk. Any fishing hazards producing high or moderate risks require investment in research and monitoring to reduce uncertainty or, alternatively, mitigating management responses (Smith *et al.* 2006).

Climate change complicates the difficulties addressing the impacts of fishing and other anthropogenic activities on fish populations. Understanding the effects of climate change on populations of chondrichthyan species in terms of abundance, distribution, and risk of extinction provides a range of additional challenges. More than ever before, this requires integration of a broad range of fields of investigation to evaluate each species' exposure to the various components of climate change. These components include increased water temperature, altered rainfall, salinity and turbidity patterns, rising sea level, increased storm strength and frequency and associated coastal erosion, changed ocean currents and upwelling, increased ultraviolet light from reduced ozone, and reduced pH (Harley *et al.* 2006). There is also a need to evaluate a species' 'sensitivity' (degree to which it responds to the exposure) and 'adaptability' (degree to which it can adjust to the exposure) to each climate change component. Risk to a species from climate change will increase or decrease depending on its life history characteristics (e.g. specialised feeding, seasonal migration dependent on synchronous events, low genetic diversity, and longevity). Risk will also change depending on a species' habitat requirements (e.g. freshwater, inshore, isolated reefs, and coral reefs).

Ecological risk assessment from each of the effects of fishing and of climate change creates a need for quantitative approaches that better parameterise biological attributes of chondrichthyan species; these parameters are the same as those required for demographic, fishery assessment, species extinction risk, and ecosystem modelling. The study of somatic growth requires wider application of stochastic models rather than simple deterministic models to represent heterogeneity in length-at-age or growth increment for addressing problems of sampling bias and length-selective fishing mortality on growth. Furthermore, in age and growth studies, there is the need to resolve uncertainty in interpretation of growth-increment bands for age determination which often differs between whole and sectioned hard part structures such as vertebrae and dorsal fin spines (Walker 1998). Investigation of reproduction requires parameters that represent maternity ogives, litter size, and sex ratio in litters. Physiological and biochemical research is required to provide a basis for determining the probability of fish survival from capture in fishing gear and from handling and discarding by fishers. In anticipation of likely redistribution of species in response to climate change, it is important to understand complex stock structuring, which will require extending application of genetic, parasite and microchemistry techniques.

New approaches to the study of fish are emerging from the application of archival, acoustic and satellite tags. Ongoing electronic miniaturization and improved battery technology is leading to the convergence of these tag types and facility for data exchange between tagged fish. Physiological and environmental monitoring probes associated with tags and capacity for transmission of data as acoustic signals to listening stations underwater and as electromagnetic signals to satellites and other receivers above water enable cost-effective remote sensing for provision of data on movement patterns, movement rates, behaviour, physiological condition, ambient conditions, and mortality of fish. Most satellite and archival tagging studies have shown that sharks range more widely (and to greater depths) than previously realised. This has major implications for the geographic scale of stock assessment and management.

Assessing the effects of fishing and climate change on chondrichthyan species within the context of ecosystem structure and function requires applying ecosystem models that incorporate fish biomass estimates, biological parameters, predator–prey relationships, and data on fishing catch and discard mass (Olaso *et al.* 2005; Sánchez *et al.* 2005). Such models can include the trophodynamics of phytoplankton, zooplankton, benthos, and demersal and pelagic communities (Baretta *et al.* 1995; Fulton *et al.* 2004*a*, 2004*b*) and evaluate the effects of various fishing gears and closed areas on chondrichthyan populations and catches. Further developments are required to link ecosystem models to global climate and oceanographic models to evaluate the potential effects of climate change.

In summary, there are immediate needs for rapid assessment techniques that provide a basis for establishing research priorities and determining chondrichthyan species at risk and in need of mitigating management. Better understanding of systems underlying sustainable use of these animals and their roles in biodiversity and maintenance of ecosystem structure and function, however, inevitably requires a long-term approach to model innovation and embracing of technological and scientific advances to obtain required data at appropriate spatial and temporal scales.

Acknowledgements

Malcolm Francis of the National Institute of Water and Atmospheric Research in New Zealand is acknowledged for suggestions on an early draft of the essay.

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