# The rivers to the sea: experiences with two endangered aquatic fish species

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ABSTRACT

There are currently 20 species, populations or communities of fish, aquatic invertebrates and marine vegetation listed on the threatened species schedules of the NSW *Fisheries Management Act 1994*. Two of these species are the eastern freshwater cod *Maccullochella ikei,* and the grey nurse shark *Carcharias taurus*. In the 1970s, well over a decade prior to their listing as threatened, there were concerns over the population status of both fish, and various actions were initiated to help preserve and maintain stocks. For example, both species were totally protected from fishing in 1984, captive breeding techniques for eastern cod were investigated and underwater surveys of grey nurse shark populations commenced. Following listing, however, there has been a significant increase in emphasis on actions to help the recovery of both species, protect their habitat and increase knowledge of their biology and distribution. In the case of eastern cod, these actions have included surveys to document the distribution of remnant and stocked populations, tagging studies, genetic and ecological research, habitat restoration works and significant input into water sharing rules for relevant catchments. For grey nurse sharks, critical habitat areas have been declared at key aggregation sites, controls placed on fishing in and around these areas, additional diver surveys completed, tagging and tracking studies commenced to provide detailed information on movements and improved population estimates, and samples collected for genetic research. The changes in management strategies resulting from the listing of these threatened species in NSW may also have flow-on benefits for other aquatic species.

Key words: endangered, fish, grey nurse shark, eastern freshwater cod.

## Introduction

In New South Wales, the primary responsibility for the conservation of biodiversity is shared between two agencies: the Department of Environment and Conservation (DEC) (formerly the NSW National Parks and Wildlife Service) through its administration of the *Threatened Species Conservation Act 1995*, and the Department of Primary Industries (formerly NSW Fisheries) through its administration of the *Fisheries Management Act 1994*. DEC is responsible for the conservation of four vertebrate groups (mammals, reptiles, birds and amphibians), and also for terrestrial invertebrates and freshwater plants. The Department of Primary Industries is responsible for the conservation of all 'fish', which includes vertebrate fish and all aquatic invertebrates (both freshwater and marine), and 'marine vegetation' which includes mangroves, seagrasses and macroalgae.

Historically, the main focus of NSW Fisheries had been to regulate fishing and fish farming industries. In the late 1970s through to the early 1990s, amendments to the then *Fisheries and Oyster Farms Act 1935* began to broaden the department's role to include the total protection of certain species of fish from being caught and killed, the declaration of aquatic reserves, controls on dredging and reclamation as well as a range of other measures aimed at the protection of fish habitat. This trend continued with the introduction of the new *Fisheries Management Act* in 1994, which included specific objectives relating to ecologically sustainable development and the conservation of biological diversity.

In 1998, threatened species provisions paralleling those of the *Threatened Species Conservation Act* were introduced into the *Fisheries Management Act*. These provided a comprehensive framework for the protection and recovery of threatened species, populations and communities of fish, aquatic invertebrates and marine vegetation, allowing for the development and implementation of recovery and threat abatement plans and the identification of critical habitat for endangered species. Consequential amendments to the *Environmental Planning and Assessment Act 1979* required specific consideration of the impacts of developments and activities on threatened species, populations or ecological communities during environmental planning and assessment.

Currently 7 endangered species, 2 endangered populations, 2 endangered ecological communities, and 8 vulnerable species are listed under the *Fisheries Management Act*. These range from large, conspicuous 'icon' species such as the eastern

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freshwater cod *Maccullochella ikei* and grey nurse shark *Carcharias taurus* to smaller, less well known species such as the southern pygmy perch *Nannoperca australis* and Buchanans fairy shrimp *Branchinella buchananensis*. In addition, one species (a seaweed) is listed as 'presumed extinct'.

The threatened species approach to biodiversity conservation has been criticised on a number of counts. For example, it has been criticised on the basis that it requires relatively good species-level knowledge, is resource-intensive and costly, reactive rather than preventative, and tends to be biased towards highly visible, 'appealing' species (e.g. New 1995; Reed and Clunie 1997; Yen and Butcher 1997; Woinarski and Fisher 1999; Ponder *et al.* 2002). This has led some critics to call for a broader approach which operates at the level of communities, ecosystems, or threatening processes (*e.g.* Franklin 1992; Bowen 1997; Reed and Clunie 1997; Tear *et al.* 1995; Walker 1992). However, as experience with some of the listed fish species in NSW has demonstrated, threatened species listings can provide a powerful tool in leveraging environmental outcomes on complex issues. Outcomes include raising community awareness of aquatic biodiversity and conservation, gaining support for additional research, and delivering specific actions, such as habitat protection, which have significant flow-on benefits for associated species. Within NSW Fisheries, the threatened species legislation has also played a major role in strengthening the department's commitment to biodiversity conservation, with staff from a range of programs (including environmental assessment, habitat protection and rehabilitation, fisheries management, conservation research, and compliance) now playing key roles in threatened species-related work.

This paper summarises the conservation history of two species that have been a major focus of the NSW Fisheries threatened species program to date; the eastern cod and grey nurse shark. Both were listed in 1984 as totally protected under section 19 of the *NSW Fisheries and Oyster Farms Act*, and subsequently as threatened species under the *Fisheries Management Act*. Some background information on each species is given, together with a summary of changes in the management approach as a result of listing, focusing on key issues (e.g. the influence of the eastern cod's requirements in the development of water sharing plans, the declaration of critical habitat for grey nurse sharks and the significant additional research undertaken to address major information gaps). The implications of these actions for broader biodiversity conservation are also discussed.

## Case study 1. Eastern cod

### *Background information*

The eastern cod (Figure 1) is a large, predatory, freshwater fish native to only the Clarence and Richmond Rivers in northern New South Wales. It is closely related (and similar in appearance) to the Murray cod *Maccullochella peelii peelii* and the trout cod *Maccullochella macquariensis*, both from the inland Murray-Darling River system, and the Mary River cod *Maccullochella peelii mariensis* from the coastal Mary River system in southern Queensland.

Eastern cod have been recorded up to 41 kg and over 1 metre in length, although such large fish are rare with most individuals normally less than 5 kg and 70 cm in length (Rowland 1996). They are often found in clear, flowing streams with rocky beds and deep holes, generally in areas with plenty of instream cover such as boulders or large woody debris (snags) (Rowland 1993, 1996; Butler 2000; Figure 2).

Eastern cod were once abundant within the Clarence and Richmond Rivers downstream of tablelands waterfalls (Figure 3), and were an important food fish for early settlers in the region. Populations of the species apparently collapsed in the 1920s and 1930s (exacerbated by a series of major fish kills in the late 1930s), and they continued to decline until the 1980s (Rowland 1993, NSW Fisheries 1999). Development in the catchment for such activities as farming, urban development and mining has had significant effects on the Richmond and Clarence river systems, and the decline of eastern cod is probably attributable to a combination of over-fishing and habitat modification (including sedimentation, snag removal, flow modification, water pollution and barriers to migration).

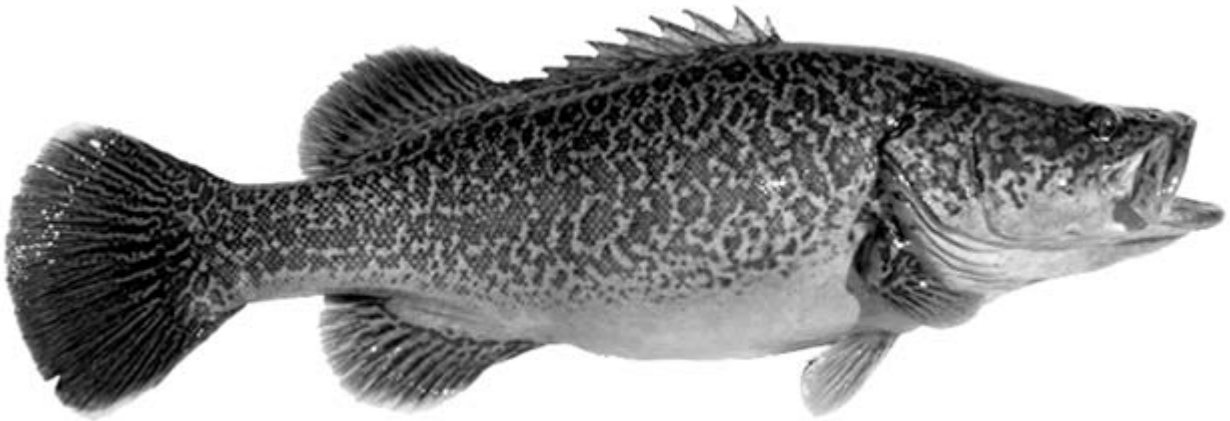

**Figure 1.** The eastern freshwater cod *Maccullochella ikei.* Photo: NSW Fisheries

**Figure 2.** Habitat of eastern cod in the Nymboida River, north-eastern NSW. Photo: NSW Fisheries

Eastern cod was first formally described as a separate species in 1985, after a study on Murray cod identified (through electrophoretic and morphometric data and a cross breeding experiment) that cod from north-eastern NSW were a separate species (Rowland 1985).

This work led to the species being protected from harvesting in 1984, under section 19 of the *NSW Fisheries and Oyster Farms Act*. By this time they were already considered to be extinct in the Richmond River system, very rare or absent in the major northern tributaries of the Clarence River catchment, absent from the Orara River, and present only in small numbers in a few other southern tributaries of the Clarence River (principally the Mann and Nymboida Rivers; see Figure 3), where some pristine habitat still remained (Rowland 1993). By the early 1990s, anecdotal reports from anglers suggested

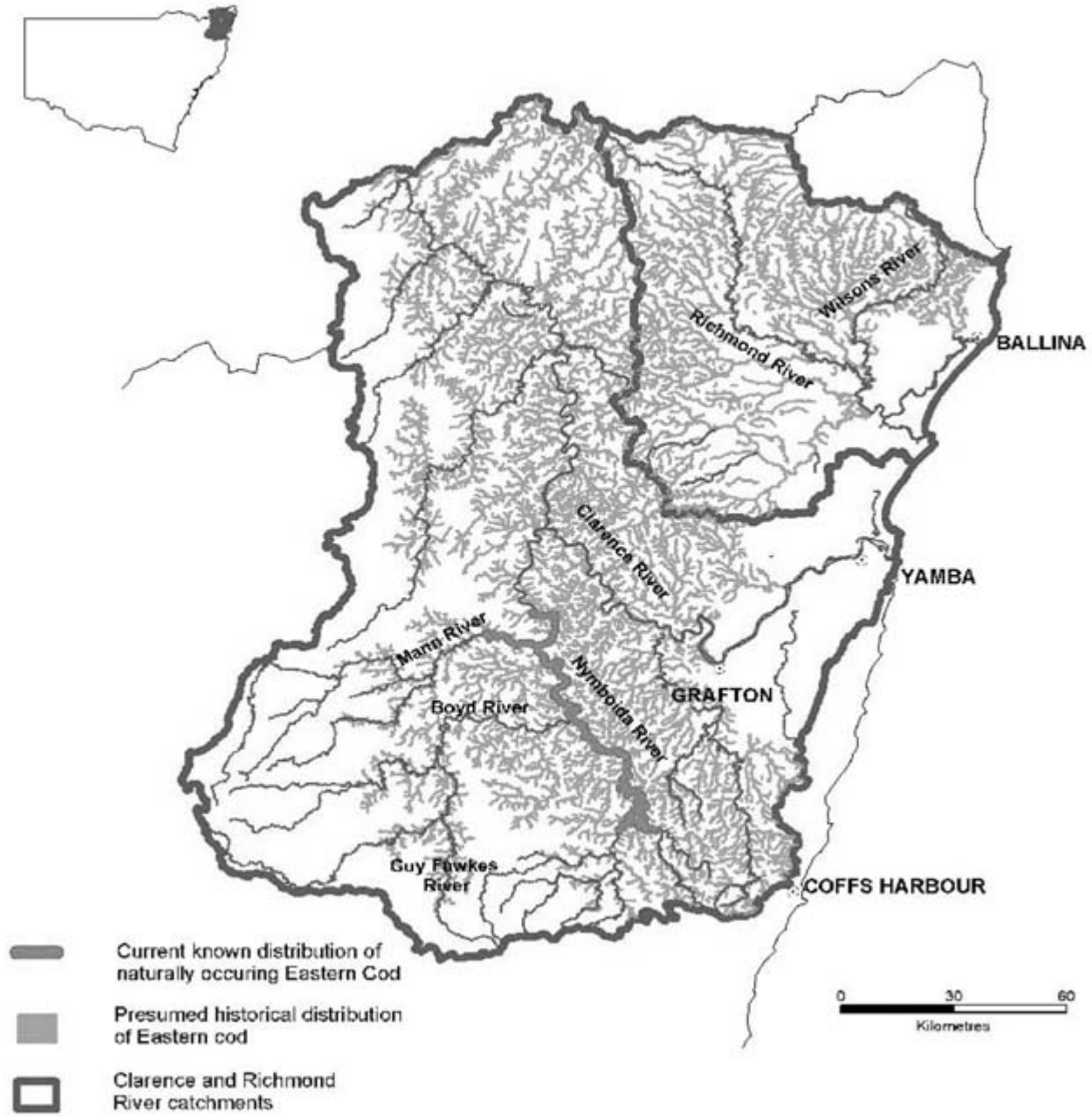


**Figure 3.** Historical distribution of eastern cod and suspected range of remnant wild population in north-eastern NSW

that their numbers had increased to the point where they were being caught more regularly in a wider area of the Clarence system, but there was little scientific evidence to confirm this. More rigorous surveys suggested they remained highly restricted in distribution.

The eastern cod was listed in 1992 as an endangered species under the Commonwealth *Endangered Species Protection Act 1992*. With the introduction of the threatened species provisions of the *Fisheries Management Act* in 1998, eastern cod was placed directly on Schedule 4 of the Act (endangered species), together with two other freshwater fish species recognised as being of significant conservation concern (trout cod *Maccullochella macquariensis* and Oxleyan pygmy perch *Nannoperca oxleyana*). Eastern cod was also listed as critically endangered on the World Conservation Union (IUCN) 'Red List' of threatened species in 1996 (Baillie and Groombridge 1996).

## Management activities prior to listing in NSW

As eastern cod is a large, identifiable fish and a popular angling species, its decline was clearly recognised long before the introduction of the NSW threatened species legislation. Concern over its status led to the initiation of some conservation actions by government agencies and community groups, most notably its total protection from fishing in 1984 and the development of a captive breeding and restocking program shortly afterwards.

Captive breeding techniques for eastern cod were developed by NSW Fisheries between 1988 and 1990 at the Grafton Research Centre, and approximately 30,000 fingerlings were stocked into various locations in the Clarence and Richmond river catchments (including impoundments) at that time. However, no large-scale surveys were carried out to determine the distribution of eastern cod or the survival of the stocked fish.

In 1994 NSW Fisheries issued a permit to a private hatchery at Dorrigo, Booma Fisheries, to undertake further work on the breeding and stocking of eastern cod. This was on the proviso that strict genetic protocols were followed (to prevent loss of fitness through inbreeding depression and maximize available genetic variation in the recovering population) and hatchery-reared fish were used for conservation purposes only. Booma Fisheries stocked 660 fingerlings in 1996 and 30,000 in 1997.

In 1997 a non-profit community group, Project Big Fish, began promoting the conservation of eastern cod with a major focus on raising funds for stocking. NSW Fisheries and Project Big Fish also worked to raise public awareness of the threats to eastern cod through a wide range of activities including signage, media releases and interviews, magazine articles, brochures, newsletters, field days, presentations to schools and community groups and information on the internet.

Some population survey work was also conducted (Faragher *et al.* 1993). However, there was still very little information on many aspects of the species' biology, or even its geographical distribution.

## Management activities following listing in NSW

Recovery planning for eastern cod commenced shortly after it was listed as endangered in 1998. In 1999 NSW Fisheries received funding through a threatened species grant under the Natural Heritage Trust to develop the NSW and Commonwealth recovery plan and conduct survey and monitoring work. A recovery planning team was established, and the draft recovery plan was publicly exhibited in November 1999 and finalised in May 2004 (NSW Fisheries).

The draft recovery plan provided for the continuation and expansion of activities that had been initiated prior to listing, such as the captive breeding and restocking program and community education activities. However, it also emphasised the importance of further research to gain a greater understanding of the size, distribution, ecological requirements, historical and existing genetic status of the eastern cod population and the threats to its survival. The plan also recognised the need to initiate management actions to reduce identified threats such as impacts from development and natural resource use on water quality, water flows, and habitat quality (NSW Fisheries 1999).

### Research

A threatened species grant obtained under the Natural Heritage Trust enabled NSW Fisheries to commence a series of surveys (still ongoing) at a range of sites in the Clarence and Richmond catchments. The aim of this survey program has been to document the distribution of remnant and stocked populations, estimate their relative abundance, examine population structure, survival and recruitment, assess habitat preferences and develop methods to monitor the status and recovery of eastern cod over the long term (Figure 4). Captured eastern cod

**Figure 4.** Electrofishing for eastern cod in the Clarence River. Electrofishing works by generating an electric field in the water through a cathode and anode connected to a control box which is mounted on a boat, in a backpack unit, or on the bank. Fish in the vicinity are initially drawn towards the anode, but are then immobilized, allowing them to be collected from the surface. The advantages of electrofishing are that it can be done relatively quickly, used in areas which are difficult to access with other gear types, and the fish recover within a few minutes of collection allowing them to be returned unharmed to the water. Photo: NSW Fisheries

have been fitted with Passive Integrated Transponder (PIT) tags before release (Figure 5), enabling fish recaptured during subsequent surveys or by Project Big Fish volunteers to be 'scanned' to obtain valuable data on movements, growth and abundance. To date 340 cod have been tagged, with preliminary results suggesting strong site associations of fish to specific river reaches or pools and highly variable growth rates (Pollard and Wooden 2002, I. Wooden pers. comm. 2004). Tissue samples (fin clips) have been collected from captured fish to assist in genetic research by Southern Cross University. Some angling has also been conducted, with the assistance of Project Big Fish, to extend the distributional data and genetic sample collection. A PhD student is currently investigating the ecology of eastern cod, and has obtained significant new information on its reproductive biology and behaviour, including video footage of individuals guarding the eggs (G. Butler, Southern Cross University, pers. comm. 2004).

**Figure 5.** Inserting a Passive Integrated Transponder (PIT) tag into a captured eastern cod. Photo: NSW Fisheries

Additional funding for research and recovery actions has been received from other sources including the Recreational Fishing (Freshwater) Trust Fund and water supply authorities, the latter as a form of environmental offset against potential impacts from high-priority works. In 2003, NSW Fisheries also received funding from the NSW Environmental Trust to undertake habitat restoration works (such as revegetation, improvements to fish passage, and fencing) along a 'demonstration reach' in the Richmond River catchment, and to monitor any changes in eastern cod populations resulting from the habitat restoration work.

## Water reforms process

The Clarence and Richmond River systems are largely unregulated, but natural flow patterns have been altered by increasing levels of water extraction for a variety of uses (eg. irrigation, town water supply, stock watering and power generation). The draft recovery plan (NSW Fisheries 1999) recognised that although little information existed on the amount of water extracted or its impact on river health, alteration of natural flows was likely to be a major issue in the management of eastern cod populations. Extraction of water can affect habitat connectivity and quality, both key requirements for the survival of eastern cod. Alteration of flows, particularly during critical lifecycle phases (e.g. pairing and site selection), has been hypothesised to result in reduced fecundity. Furthermore, habitat changes such as reduced water quality, sedimentation of riffle zones and pools and reduced diversity of macrophytes can not only affect eastern cod directly but may also have negative impacts on prey species and general river health and resilience.

In 2000, a new *Water Management Act* was introduced in NSW to provide for the sustainable management of the State's water resources. Local water management committees were established for a number of priority areas throughout the State, with the task of negotiating agreement on water sharing rules as the basis for 10-year water sharing plans.

Protection of the environment is foremost in the objects and principles of the Act, which states that sharing of water from a water source must protect that water source and its dependent ecosystems, and that water sharing plans must establish environmental water rules. However, the precise nature of these rules (e.g. the level at which users must cease to extract water to protect low flows) has been the subject of intense negotiations among the various representatives on the committees, with decisions having major social and economic as well as environmental implications.

A key action in the draft recovery plan for eastern cod was to ensure that the flow requirements of eastern cod were supported during the water reforms process. Given the lack of specific, quantitative information on the biology or habitat needs of eastern cod, NSW Fisheries organised an expert panel of managers, researchers and external experts to define the minimum flow requirements at various times of the year for recruitment, spawning and juvenile dispersal. The panel used expert opinion and available information on the size, timing of reproduction and habitat preferences of eastern cod to recommend:

- a minimum water depth of 30 cm over riffles and a flow velocity not greater than 1.5 m/s (to allow movement of eastern cod between pools, particularly from late June to March during spawning, larval growth and recruitment phases);
- the maintenance of stable water depth of at least 1.5 m in pools (particularly during August-October to protect nest sites and habitat for spawning adults); and
- limiting extraction to mimic medium to high flow events (NSW Fisheries 2000).

Following this process, agreement was reached with the (then) Department of Land and Water Conservation (now Department of Infrastructure, Planning and Natural Resources) to undertake flow modelling to estimate the percentile flows and extraction rules that would correlate with the recommended water depths over riffles and in pools.

NSW Fisheries provided advice to two water management committees (WMCs) dealing with three subcatchments within the range of eastern cod; the Northern Rivers WMC (for Coopers Creek, in the Richmond catchment) and the Upper North Coast WMC (for the Dorrigo Plateau and Orara River, in the Clarence catchment). Although eastern cod are present in all three sub-catchments, the environmental characteristics, current status of eastern cod, and socio-economic issues differ markedly, and this is reflected in the different flow rules that were achieved in each case (Table 1). For Coopers Creek and Dorrigo Plateau, for example, the degraded state of habitat and the existence of significant socio-economic issues meant that full conformity with the eastern cod flow requirements was not achievable.

The Orara River, by contrast, contains some high-quality areas of remaining habitat and had the potential to contribute significantly to the recovery of eastern cod. The WMC was first provided with information on the river system and the linkages between eastern cod and other elements of the ecosystem (e.g. invertebrate food resources), as many members of the committee had little background in, or understanding of, riverine ecology. Subsequently, intensive field work was conducted (in collaboration with staff from other agencies) to validate the earlier flow modelling work and determine the specific river flows needed to meet the requirements of eastern cod. This provided information in a form consistent with flow modelling programs, which was readily understood by the committee. This field-validated information was used in subsequent negotiations when the environmental benefits of improved flows had to be weighed against the potential social and economic impacts.

The eventual outcome was a unanimous decision by the committee to support a set of water sharing rules which included progressive increases in the 'cease to pump' (CTP) threshold over the life of the water sharing plan, the establishment of a 'cod hump' (higher CTP threshold during the critical months when eastern cod migrate) for the first 5 years of the plan, and the establishment of rules for various flow classes. These rules, when implemented, will provide significant improvements in low flow protection, will better mimic natural flow variations, and will benefit not only eastern cod but also the other aquatic species and the broader ecosystem of the Orara.

Monitoring of a range of hydrological and ecological features in the Orara River will be ongoing as part of the NSW water reform process and the Department of Primary Industries eastern cod research program. Performance indicators and associated adaptive management responses will provide a basis for the long-term management of eastern cod populations.

## Case study 2. Grey nurse shark

### Background information

The grey nurse shark (Figure 6) is a large species of shark native to subtropical and cool temperate waters in the Mediterranean Sea and the Atlantic, Indian and Pacific Oceans. In Australia, grey nurse sharks were historically found around much of the coastline including southern Queensland, New South Wales, Victoria, South Australia and southern Western Australia. The species is now restricted to two separate populations, one off NSW and southern Queensland, and the other off Western Australia (Otway and Parker 2000; Otway *et al.* 2003).

**Table 1.** Comparison of flow rules contained in water sharing plans for the Orara River, Coopers Creek and Dorrigo Creek.

| Water sharing plan | Cease to pump | Do flow rules achieve recommendations of recovery planning? |
|---|---|---|
| Orara River | 80%ile^<br>(yr 6-10, #critical month all zones) | Yes<br>(require structural adjustment for change in rules in years 6-10) |
| Coopers Creek | 14-31*-14 ML/d<br>(97-95*-97%ile)<br>(#critical month) | Partial<br>(significant socio-economic impact)<br>(*cod hump – July to September migration period) |
| Dorrigo Plateau | Zone 1: 75ML/d (98%ile)<br>Zone 2: 23ML/d (99%ile)<br>Zone 3: 17ML/d (97%ile)<br>Zone 4: 13ML/d (98%ile) | No<br>(Significant socio- economic impact, limited habitat availability, possibly outside of natural range). |

*Cod hump = jump in Cease To Pump during migration periods to provide for greater depth over riffles (ie. allows for greater fish passage)

^ percentile = % of time that this flow is exceeded

#critical month = the one month in the year when irrigation demand for water is most close to exceeding, or exceeds, the available flows.

**Sources:** Water Sharing Plan for the Orara River (draft), Water Sharing Plan for the Coopers Creek Water Source 2003 (Gazetted 14 February 2003), Water Sharing Plan for the Dorrigo Plateau Surface Water Source and the Dorrigo Basalt Groundwater Source 2003 (Gazetted 21 February 2003).

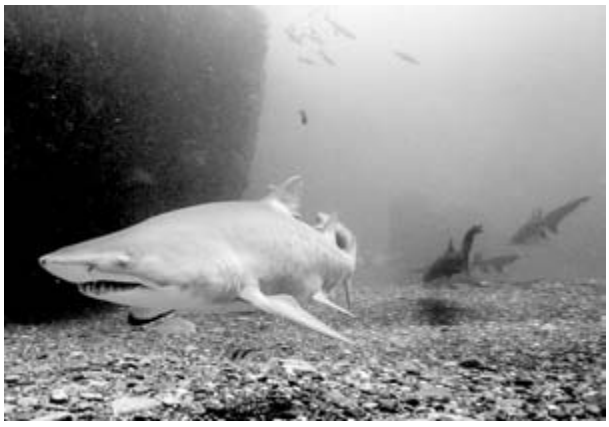

**Figure 6.** The grey nurse shark *Carcharias taurus.* Photo: David Harasti

Grey nurse sharks are regularly seen by divers in a relatively small number of areas along the NSW coast and in southern Queensland, usually in or near deep, sandy-bottomed gutters or caves around rocky reefs or islands fairly close to shore. Despite their fierce appearance, grey nurse sharks are not considered dangerous and generally pose no threat to divers or swimmers unless provoked (Pollard *et al.* 1996).

The life-history and reproductive strategies of the grey nurse shark make it particularly vulnerable to human-induced pressures. Their practice of aggregating at inshore rocky reef sites of the type that are often subject to heavy fishing pressure makes them vulnerable to incidental capture or injury. The grey nurse shark is one of the least fecund of all sharks with females producing an average of one pup per year. This low reproductive rate and their apparently slow growth rate mean that populations, once reduced, will take a long time to recover (Otway *et al.* 2003).

Grey nurse shark populations were reportedly the target of commercial fishing activities in a number of areas in NSW from the mid 1800s up until the Second World War. Between the 1950s and the 1980s grey nurse shark numbers showed a serious decline in NSW waters, largely attributed to the impact of commercial fishing and recreational spear and game fishing, as well as shark control activities such as beach meshing (NSW Fisheries 2002). In October 1997, the grey nurse shark was listed as a threatened species under the *Commonwealth Endangered Species Protection Act 1992.* In NSW it was listed as "vulnerable" under the *Fisheries Management Act* in May 1999 and subsequently upgraded to "endangered" in August 2000. Current threats to grey nurse sharks include death and injury resulting from incidental capture by fishers, as well as illegal fishing activities such as shark finning (i.e. where the fins are cut off and retained for sale and the carcass dumped at sea) (NSW Fisheries 2002).

## Management activities prior to listing in NSW

During the 1950s and 1960s grey nurse sharks were falsely viewed as maneaters, and many were deliberately killed during highly publicised operations by spearfishers and scuba divers using powerheads (Ireland 1984). In addition, from 1961 to 1980 over 400 grey nurse sharks were recorded as being caught by game fishing clubs in NSW (Pepperell 1992).

A decline in the proportion of grey nurse sharks caught by gamefishers was clearly evident over the period from 1960 to the 1970s (Environment Australia 1997). Shark meshing captures also showed a significant decline during this period (Figure 7). Gamefishers voluntarily banned the capture of grey nurse sharks in 1979 (Marsh 1995). In the late 1970s and early 1980s a number of underwater film makers, scuba divers and spearfishers began calling for protection of the shark. Following consultation with peak recreational fishing, commercial fishing and scuba diving groups, the species was totally protected from being captured and killed in November 1984 (Pollard *et al.* 1996).

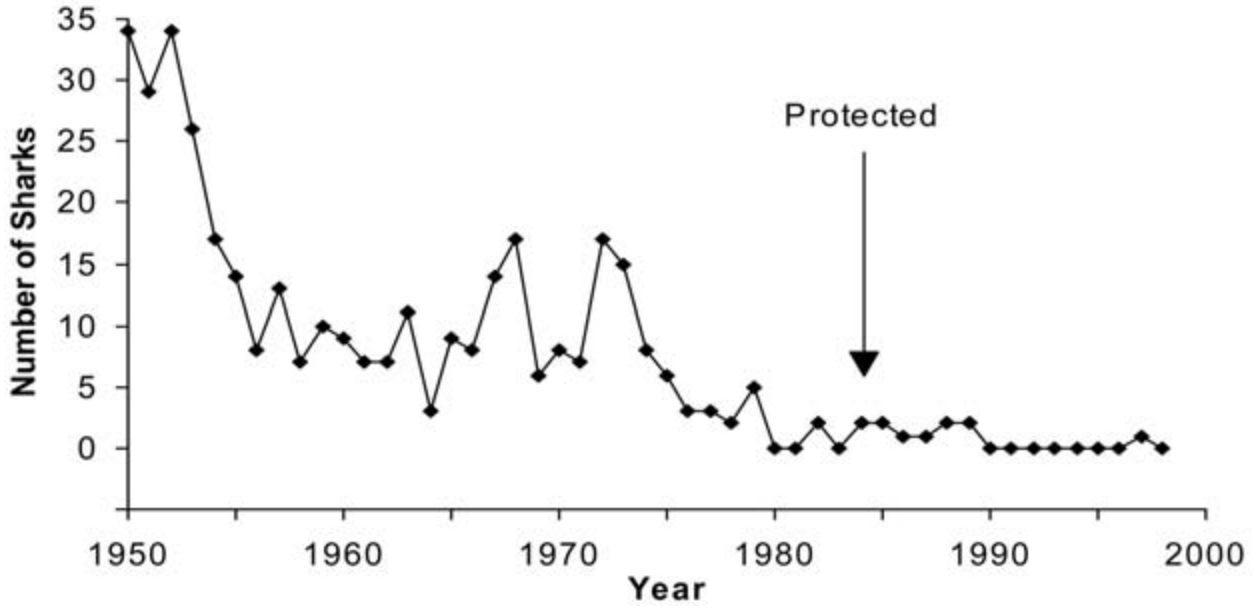


**Figure 7.** Decline in the numbers of grey nurse sharks caught in shark meshing nets in the Newcastle/Sydney/Wollongong regions from 1950-1998 (from: Otway and Parker 2000)

### Research

Prior to the grey nurse shark being listed as threatened in NSW, much of the scientific information about the species' biology (e.g. behaviour, reproduction, age and growth, migration patterns, diet and feeding habits) had been derived from studies in the USA and South Africa.

It was not clear whether this information could be applied in the Australian context. In particular, spatial and temporal patterns in the abundance of grey nurse sharks in south-eastern Australia were not well understood. The data that did exist came primarily from records of captures in the NSW beach meshing program, gamefishers' log books and three diver surveys. These surveys provided some information on local abundance and movement, but they involved studies on a small spatial scale over relatively short periods of time (Otway and Parker 2000).

Although grey nurse sharks were listed as threatened in NSW in 1999, the species had already received national listing two years earlier. Consequently, in 1998 NSW Fisheries was able to begin a large-scale study funded by a threatened species grant under the Commonwealth's Natural Heritage Trust program. This study involved replicate diver surveys of all known grey nurse shark aggregation sites along the entire NSW coast, the mapping of the key sites from south of Sydney to the Brisbane area and an investigation of the potential to declare the important sites as marine protected areas to facilitate the recovery of the species.

Three NSW coastwide surveys were carried out in November/December 1998, March/April 1999 and June/July 1999. The maximum number of grey nurse sharks observed in any one survey was 207. These results indicated that the total number of grey nurse sharks was very low and suggested that the population in NSW had not recovered since the species was first protected in 1984 (Otway and Parker 2000).

## Management activities following listing in NSW

Following publication of the report by Otway and Parker (2000) the conservation status of grey nurse sharks was re-assessed and the listing upgraded from vulnerable to endangered in August 2000. NSW Fisheries released a draft grey nurse shark recovery plan for community comment in May 2002 (NSW Fisheries 2002). The draft plan detailed actions required to promote the recovery of the species in NSW waters including a recommendation to declare all known major grey nurse shark aggregation sites as critical habitat areas.

In December 2002, 10 sites were declared as critical habitat and new arrangements were put in place to protect the grey nurse shark. Within critical habitat areas and surrounding 800 metre buffer zones, controls were placed on those forms of fishing thought to pose a significant risk of incidental capture and on diving activities likely to cause negative impacts on the sharks. For example, bans were placed on commercial set-line fishing and recreational demersal (bottom) fishing using bait from anchored boats. Bans were also placed on diving between sunset and sunrise, chasing or harassing the sharks and the use and/or wearing of electronic shark repelling devices.

Within six months of the implementation of the new arrangements, the Minister for Fisheries called for a review of grey nurse shark protection. This move was prompted by a number of factors - divers observed that the number of incidentally hooked grey nurse sharks had remained high; radio tracking studies showed sharks roamed further from aggregation areas at night than had been demonstrated in earlier work, and well outside the critical habitat areas; preliminary research results (detailed below) provided a population estimate with numbers lower than previously thought and demographic modeling indicated that the east coast population could become extinct within a few decades if fishing mortality continued at the estimated current level.

### Research

The survey report of Otway and Parker (2000) provided valuable information about grey nurse sharks at key aggregation sites including their distribution, habitat use and abundance relative to historical records. This work did not, however, provide some of the key information needed to determine the true conservation status of the species or to support decision-making on the management of the grey nurse shark population, such as the total population size or key demographic parameters.

The diver surveys developed by Otway and Parker (2000) continued for a further two years. During this time the total number of grey nurse sharks observed did not exceed 292 (Otway *et al.* 2003). In 2002 a tagging study was incorporated into the diver survey program using "roto" tags (similar to cattle ear tags) (Figure 7). This work began to provide information that was highly significant for the management of the recovery program. Standard mark-recapture techniques were used to provide the estimate that there were less than 500 individuals in the total population (Otway and Burke 2004). This work also demonstrated the considerable length of time that particular sharks spent at aggregation sites. In addition, by observing the number of grey nurse sharks that suffered imbedded hooks and hook injuries since

**Figure 8.** Measuring a grey nurse shark during tagging. Photo: NSW Fisheries

tagging, an estimate could be made of the proportion of the population that experienced incidental capture or interactions with fishing gear (Otway *et al.* 2003). Tissue samples collected during the tagging process also allowed the genetic assessment of grey nurse shark populations (Harcourt *et al.* 2003).

More recently, research using a range of "smart tags" (i.e. acoustic tracking tags, listening stations and "pop up" archival satellite tags) has been initiated to answer questions on the localized movement of sharks around aggregation sites and to determine movement patterns when they are away from these sites. An electronic tracking project found that grey nurse sharks display diurnal movements within a radius of 1200 m from a number of aggregation sites (B. Bruce, CSIRO, pers. comm.). In a project funded by Sea World and NSW Fisheries, "pop up" archival tags (i.e. tags that automatically release from the shark, float to the surface and transmit data via satellite) were fitted to three grey nurse sharks in late 2003. These tags collect data on depth, water temperature and approximate migration path for the tagged sharks. This work will provide new and detailed information on grey nurse shark movements. Preliminary results from this work strongly support current scientific opinion that the sharks are a highly inshore and coastal-dwelling species. The results do not support the hypothesis of some fishers that there is a separate, un-surveyed population in deeper waters and that the sharks occupy critical habitat sites that lie beyond normal scuba diving depths (N. Otway, Department of Primary Industries, pers. comm.).

## Discussion

The listing of threatened species under the NSW *Fisheries Management Act 1994* and subsequent recovery planning programs, while primarily aimed at the recovery of the species concerned, can also make a significant contribution to the protection and enhancement of broader biodiversity and ecosystem processes. Work to protect and restore the habitat of eastern cod, for example, particularly through involvement in the water planning process, will have positive benefits for a range of other native aquatic species and their habitats in these catchments.

The areas declared as critical habitat for the grey nurse shark support a rich diversity of marine fauna and flora, including other threatened, rare or protected species of fish. These areas will provide refuge for a range of demersal fish species as they will be protected from the types of fishing activity that would normally pose significant risk of incidental capture. Such fish include the listed threatened species black cod *Epinephelus daemelii*, a number of species protected from fishing such as the Queensland groper *Epinephelus lanceolatus* and estuary cod *Epinephelus coioides*, and species that are currently recognised as overfished such as the two species of wobbegong sharks *Orectolobus maculatus* and *O. ornatus*.

The recovery planning program also creates a greater awareness amongst the community and other stakeholders of the status of threatened species and their habitat requirements, an increased focus on issues such as research, habitat rehabilitation, and compliance and more funding for aquatic research, public education and habitat restoration. This may well lead to more opportunities and support for the conservation of threatened species and the increased protection of aquatic biodiversity. The preparation of statutory plans for the recovery of threatened species also incorporates mandatory monitoring processes to assess recovery actions, which will lead to greater knowledge about these (and other) species and the habitats they use.

## Conclusions

Aquatic systems are negatively impacted by a wide variety of human activities. For example, key threats to Australian marine and estuarine fishes are considered to be overfishing, habitat degradation and the introduction (both deliberate and accidental) of aquatic pest species (Pogonoski *et al.* 2002). Cowx and Collares-Pereira (2002) list similar threats in relation to freshwater fish species, as well as the additional factors of river impoundment, water abstraction and water quality deterioration.

These threatening processes can act alone, cumulatively or synergistically, and on-site as well as "downstream". Understanding these threats well enough to effectively develop, communicate, negotiate and deliver appropriate management responses is a difficult task. This task is confounded by a lack of detailed knowledge of the biological requirements of aquatic species and systems, and limited resources to obtain such knowledge.

It is understandable that the single species approach is often seen as an inadequate surrogate for ecosystem-based approaches, which can potentially protect a range of habitats and components of aquatic plant and animal communities without the need for detailed biological investigations of individual species. In an ideal world, decision-making on natural resource management issues would recognise and value the complex functions, requirements and interactions of all species within an ecosystem. In practice, however, many find it difficult to appreciate the complexity of functioning ecosystems or weigh their value against less 'abstract' social and economic considerations.

Our experience, as outlined in this paper, suggests that for some key issues which can threaten biodiversity, such as water extraction and fishing, single species can provide useful and relatively simple reference points and consequently act as powerful drivers of change. This can be seen particularly in those situations (such as community-based natural resource planning) where decisions on very complex issues must be negotiated by groups of stakeholders with vastly different backgrounds, experience, motives and technical understanding. In such cases, broad conservation outcomes, such as improved environmental flows, protection of key habitat areas, and increased community awareness of the issues, may well be achieved through focusing on the relatively simple requirements of a single well-known species.

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