SEDAR21-RD-22

Australian Government
Bureau of Rural Sciences

Review of information on cryptic mortality and the survival of sharks and rays released by recreational fishers

Kevin McLoughlin and Georgina Eliason

Postal address:
Bureau of Rural Sciences
GPO Box 858
Canberra, ACT 2601

Copies available from:
BRS Publication Sales
GPO Box 858
Canberra ACT 2601

Ph: 1800 020 157
Fax: 02 6272 2330
Email: salesbrs@brs.gov.au
Internet: http://www.brs.gov.au

Executive Summary

Sharks at risk from fishing

Sharks, rays and skates (collectively referred to as 'sharks' in this report) are generally considered to be at risk from fishing because of their slow growth, late maturity and small litter sizes. The 300 or more species found in Australia live in a wide range of habitats and have varied biology, behaviour, body-size and other physical attributes. The paucity of data on catches and their biology, including growth, maturity and fecundity, prevent reliable stock assessment for all but a few species. International initiatives, along with action by various levels of government and angler associations in Australia, have recognised that a precautionary approach is necessary for managing fishing activities that catch sharks.

Significant recreational catches

Recreational anglers in Australia catch over 1.2 million sharks each year, releasing more than 1.0 million of them. Many are tagged when released. However, some jurisdictions in other parts of the world are considering bans on tag-and-release fishing due to animal ethics concerns. Knowledge of the survival of released sharks is essential for (1) assessing the validity of tag-and-release for conservation, (2) estimating fishing mortality rates and (3) using the results of tagging programs in stock assessments and studies of migration patterns. This report reviews literature on the physical and physiological effects of catching and releasing sharks and approaches to tagging them.

Lack of research

There is a lack of information on the fisheries biology of sharks, including tagging and post-release survival. This is largely due to the large body-size of many sharks, low levels of funding for recreational fisheries, low commercial value of directed fisheries and because most shark catches are a bycatch of commercial fishing operations that target other species. Problems with identifying shark species contribute to difficulties in estimating catch levels and fishing mortality rates. This review identifies an expanding body of literature on tag-and-release mortality for various fish species, but there is little material specific to sharks. Most information relates to scientific approaches to tagging or commercial fisheries. National education programs on release techniques have not focused on sharks.

High survival rates

Several scientific studies of post-release behaviour indicate shark survival rates of more than 90 per cent. Those studies tend to select the healthiest individuals because they involve expensive pop-up satellite tags or acoustic tags. Survival rates of sharks released by anglers are likely to differ from those estimates because they are often released regardless of the shark's physical condition. Survival rates will also vary with species, body-size, depth of capture, ambient conditions (e.g. water temperature) and handling. Removing pelagic sharks from the water, for example, may cause physical injury because of their large size and because they must continuously swim to meet their oxygen needs. Physiological studies indicate that most sharks are able to recover from exhaustion within several hours of release.

Tagging affects survival

Tag-and-release or capture-and-release can result in mortality of the released animal. There can be infections that follow physical perforation of the skin or abrasion from the tag and physical damage to organs. Tagging may result in behavioural changes, affect predator avoidance or have sub-lethal effects on growth and reproductive success. The selection of tag types that are appropriate for the species and size of shark and education in tagging techniques will reduce mortality from tagging. Rototags or “cattle-ear tags” are widely used in scientific studies, for example, but care is required in not attaching the tags too tightly.

Improvements to release techniques

Anglers can improve the survival of released sharks by using heavier lines (which reduce play times), hastening release, removing hooks, employing appropriate handling techniques and not removing the shark from the water. The use of lures (in place of baited hooks) and barbless hooks also improve shark survival rates. Circle hooks have been shown to improve the survival of many fish species because they often lodge in the jaw. However, their benefits for sharks need investigation.

Hi-tech research

As it becomes cheaper and more reliable, improved technology in tagging will increase knowledge of shark behaviour. In particular, pop-up satellite tags will provide detailed information on the behaviour and survival of released sharks. Difficulties will remain in obtaining reliable estimates of survival rates because of variations among species, body-size, ambient conditions, play times and handling practices among anglers. Nevertheless, the results of those studies will provide guidance on the benefits of releasing sharks and advice on ways of improving the chances of released animals surviving. Conventional tagging programs could also be used to quantify the benefits of different tagging and release techniques. For example, analyses of recaptures where a shark species is tagged and released under different treatments (e.g. with and without the hook removed) would provide information on the merits of those release techniques.

Management implications

The limited literature indicates reasonably high survival rates for sharks released by scientific studies. This is likely to be due to the robust nature of sharks, their ability to recover quickly from exhaustion and low probability of being attacked by larger predators. The survival rates of sharks released by anglers are likely to be more variable and lower than those indicated in the scientific literature. The promotion of catch-and-release is therefore justified for sharks in terms of reducing fishing mortality and wastage. To improve survival rates and maximise the benefits of tag-and-release, research is required into handling techniques, tagging methods and survival rates and specific education campaigns need to be implemented.

Acknowledgements

This research project was funded by the Natural Heritage Trust (NHT). Neil Bensley, Julian Pepperell, Mark Rowsell and Peter Ward provided information and comments on drafts of this report.

Contents

Introduction

Background

There are over 300 species of Chondrichthyans (sharks, skates, rays and chimaeras) found in Australia (Last and Stevens, 1994). They live in a wide range of habitats and have varied life histories and behaviours, reflected in their morphological and physical characteristics (Musick and Bonfil, 2004). The diversity of habitats occupied by sharks means that different species are captured by a wide range of fishing gears, both recreational and commercial.

Sharks are generally characterised by slow growth, low fecundity and a close relationship between how many young are produced and the size of the breeding population. Sharks also tend to be more susceptible to overfishing than bony fish and invertebrates because they are commonly long-lived and often mature at a later age. Their life history characteristics also mean that shark stocks are slow to recover if overfished and suggest a precautionary approach is required for managing them.

One of the problems in ensuring shark sustainability is the limited understanding of these animals. Fish stock assessments require quantitative data on a range of biological parameters including growth, age at maturity, fecundity and natural mortality, as well as information on movement and estimates on the total removals due to human activities. Much of this information is poorly known for many shark species.

International concern prompted member countries of the United Nations Food and Agriculture Organisation (FAO) to develop an *International Plan of Action for the Conservation and Management of Sharks* (IPOA-Sharks) (FAO 1999). The IPOA-Sharks suggests that FAO member states should develop shark-plans to improve the conservation and management of shark stocks. In response, Australia released its *National Plan of Action for the Conservation and Management of Sharks (*Shark-plan*)* in 2004 to provide guidance as to how the conservation and management of sharks can be integrated into management arrangements for target and non-target fisheries by the jurisdictions responsible for those fisheries (SAG, 2004). The Shark-plan identified multiple issues to be addressed and actions to be undertaken, including the need for an assessment of handling practices for the conservation and management of sharks.

There are two main categories of recreational angling; competition gamefishing and general recreational angling. Tuna and billfish are the most sought after species by gamefishers, but sharks are also caught and occasionally targeted. Recreational anglers chiefly target bony fish, though sharks and rays are also often taken and sometimes targeted (Rose, 2001). There are some data available on sharks taken by gamefishing through various programs which are outlined below. However, some species of sharks, skates and rays are not easily identified and information at the species level can be poor. Data at the species level for sharks, skates and rays from general recreational angling is particularly limited.

The adoption of catch-and-release and tagging by recreational anglers can be a valuable conservation tool and high numbers of fish, including sharks, are released by anglers and gamefishers. With an adequate sampling regime, tagging can provide basic biological information on migration, age and growth, natural mortality and behaviour, as well as comparative catch levels among sectors. However, the extent of post-release mortality of released fish is not well known and is an important consideration in evaluating the benefits of catch-and-release or tag-and-release by recreational anglers. This report examines research available on the physiological effects of catch-and-release fishing and current best-practice approaches to the tagging of sharks. It should be noted that some jurisdictions are examining bans on tag-and-release fishing due to animal ethics concerns (e.g. Switzerland has announced a ban to come into effect in 2009).

The term ‘cryptic mortality’, as used in the report, refers to the unobserved death of animals following capture and release. The report examines available information on the cryptic mortality and sub-lethal effects of recreational angling for sharks and rays (the term ‘sharks’ is used throughout the report to include sharks, skates and rays; “fish” refers to bony fish or “teleosts”).

The effects of capture, tagging and release can vary from immediate and obvious to delayed and unobserved after release. Not all effects are lethal. Immediate cryptic mortality can result from hook damage, damage due to handling and tagging, and post-release predation. Delayed cryptic mortality may result from stress, internal damage to organs and backbone caused by handling out of water, poisoning and infection (from wounds, hooks and tags). Sub-lethal effects include changes in behaviour and reproductive ability, infection and lowered immune response and reduced growth rates. Long playing (or 'fighting') time by anglers after hooking may exhaust the shark and potentially result in death. Behavioural changes after release are also possible but are difficult to quantify and consequently, are not covered in this report. Time out of water also contributes to subsequent survival (Casselman, 2005). Sharks suffering any of these effects are at greater risk of predation.

Conservation, policy and research initiatives

Over the last decade there has been a growing international focus on proactive and precautionary management of the oceans' resources. This can be traced back to the FAO *Code of Conduct for Responsible Fisheries* (FAO, 1995) where it is recommended that:

> *"States should ensure that their fisheries interests, including the need for conservation of the resources, are taken into account in the multiple uses of the coastal zone and are integrated into coastal area management, planning and development".*

The code stresses that a lack of scientific information should not be used as a reason for postponing or failing to take conservation measures.

Australia has undertaken a number of initiatives to ensure the sustainability of resources, for both marine and freshwater environments, both at the state and Commonwealth level. In 1996, the Commonwealth, state and territory governments endorsed the *National Strategy for the Conservation of Australia's Biological Diversity* (NSCBD). The NSCBD recommends information is needed to improve the knowledge base to assess the impact of recreational angling on fisheries, fish and their habitats.

The Victorian Government's Fisheries Regulations 1998 provide an example of typical state government regulations. These regulations require the return of fish to water (except noxious aquatic species) with the least possible injury or damage where:

- the fish is taken during a closed season for the species
- the fish is taken from a water closed at the time to the taking of the particular species
- the fish is of a length that is below a prescribed minimum legal length
- taking the fish will exceed the catch limit for the species
- the fish is legally takeable but is not to be kept as food or bait for personal use.

The introduction of the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) refocused the national commitment to wildlife protection. In the same year, the FAO produced the IPOA-Sharks and Australia subsequently developed its Shark-plan providing a focus for shark management and research.

The National Recreational Fishing Policy (1994) recommends that anglers 'co-operate in recognized fish tagging programs for research purposes' (DAFF, 1994). The *National Strategy for the Survival of Released Line-caught Fish* (NSSRLCF) was initiated by the Fisheries Research and Development Corporation in 2002 and completed in 2008 (Anon. 2007a). The NSSRLCF has supported projects aimed at improving the survival of released line-caught fish through:

- a better understanding of the effects of fishing
- an increased adoption of best practices in handling fish

The NSSRLCF also seeks to improve fisheries management through:

- a reduction in the total mortality of released line-caught fish
- the inclusion of recreational catch and fish survival data in fisheries stock assessment.

The NSSRLCF also publicises the results of the numerous research projects and promotes advancements in catch-and-release techniques. Priority species groups and iconic species have been identified for targeted research but shark species have not been included to date. Of the large amount of educational fish handling material produced under the strategy, only one brochure describes the best practices in releasing sharks and rays (Released Fish Survival Fact Sheet, Appendix 1). There are very few studies on the survival of catch-and-released sharks and this brochure gives a knowledge rating of three for sharks and rays, where five indicates sufficient knowledge of fish released survival rates and best practices for the species (http://www.info-fish.net/releasefish/). A similar brochure has been produced by the Queensland Environmental Protection Agency (Anon. 2007b, Appendix 2).

The National Recreational and Indigenous Fishing Survey of Australia (NRIFS) (Henry & Lyle, 2003) was commissioned by the Commonwealth Government to collect nationally consistent and comparable statistics on fish catch and effort for the non-commercial components of Australian fisheries. The survey also sought to examine the attitudes and awareness of participants to management issues, research and compliance programs and their motivation for recreational angling. The NRIFS also conducted surveys of tackle shops on the use of "friendly fishing gear", as well as an education campaign on releasing line-caught fish, which involved television, print media, posters and pamphlets. In addition, surveys of recreational anglers were undertaken before and after the national survey to gauge the success of this campaign.

The NRIFS estimated that 3.36 million Australian residents, aged 5 years or older, fished at least once in the 12 months prior to May 2000 (Henry & Lyle, 2003). It also estimated that approximately 228 000 sharks and rays were caught and retained by recreational anglers over the 12-month period, and a further 1.02 million were released (i.e. 81.8 per cent of the total catch of sharks and rays were released, the highest of all species groups). Approximately 50 per cent of retained specimens were reported as caught in coastal waters, 40 per cent in estuarine waters and 10 per cent in offshore waters. Unfortunately, reporting of shark and ray catch to the species level was poor, though some species-specific information is available for some regions. There is no information from the survey on the condition of released specimens. The NRIFS found that of the anglers surveyed, 88 per cent stated that they had released fish in the past one to two years.

Further studies on the species taken and post-release survival are required for assessing the impact of recreational angling for sharks and rays. Recreational angling is primarily a responsibility of state and territory governments and is important for the economies of many communities throughout Australia. Significant research programs into recreational angling are supported by state and territory governments. Support for studies has also been provided through the *Recreational Fishing Community Grants Program* (DAFF, 2006), administered by the Department of Agriculture, Fisheries and Forestry, that seeks to achieve a number of outputs, including *'to increase the capacity of local recreational fishing groups and communities through activities such as monitoring programs, tagging projects and data collection'*. The guidelines were developed to ensure that tagging applications are supported by a comprehensive feasibility study and co-signed by a state or Commonwealth scientific research agency.

Catch-and-release and tagging

'Catch-and-release' and 'tag-and-release' have become part of the culture of recreational angling in Australia, as evidenced by the prevalence of the activity and its promotion on many recreational angling television shows. However, there are concerns with tag-and-release, particularly if the angler is not trained in the correct procedures. This is principally due to handling and tagging techniques that may lead to increased mortality rates in released fish.

The willingness of recreational anglers to release their catch has been attributed to an increased community awareness of sustainability issues. Decreased bag limits and increased restrictions on legal length of fish have probably also contributed to the trend to release more fish (InfoFish website http://www.info-fish.net/releasefish/).

The Australian National Sportfishing Association (ANSA) and the Game Fishing Association Australia (GFAA) are recognised as peak recreational angling organisations. Under tournament conditions excellent records are kept of most captures. By comparison, small and non-club recreational fisheries suffer a lack of information. The GFAA have defined the following shark species or groups of species as eligible in contests:

- Eagle ray (*Myliobatis australis*)
- Blue shark (*Prionace glauca*)
- Tiger shark (*Galeocerdo cuvier*)
- Gummy shark (*Mustelus antarcticus*)
- Porbeagle shark (*Lamna nasus*)
- Hammerhead sharks (*Sphyrna* spp.)
- Mako sharks (*Isurus* spp.)
- Thresher sharks (*Alopias* spp.)
- Whaler sharks (*Carcharhinus* spp.).

ANSA's list of eligible species includes the above, except for Porbeagle sharks, as well as:

- Common sawshark (*Pristiophorus cirratus*)
- Southern sawshark (*Pristiophorus nudipinnis*)
- School shark (*Galeorhinus galeus*)
- Seven gill shark (*Notorhynchus cepedianus*)
- Rays (Families Dasyatididae, Myliobatididae, Rajidae, Rhinobatidae, Rhynocobatidae and Urolophidae).

The Austag program is an umbrella for ANSA-managed state government fisheries tagging programs, jointly run by Austag branches and state fisheries agencies. The national Austag program promotes the tag-and-release of line-caught fish. A comprehensive Austag Trip Report form is available to anglers who participate in the voluntary tagging program (http://www.infofish.net/releasefish/). SUNTAG, the Queensland branch of Austag provides several information brochures on the *InfoFish* website including basic tagging techniques, how to record hook locations, measuring fish, handling and releasing finfish. Shark handling and tagging *per se* is not highlighted in the ANSA, GFAA or Austag literature.

According to the Game Fishing Tournament Monitoring Program 1993-2000 (Murphy et al. 2002), 16 per cent of gamefishing tournaments on the east coast target sharks (1378 shark boat fishing days and 6325 shark angler trips from 1996–97 to 1999–2000) (the region in the study was from south-east Queensland to southern NSW). In this study, 40.1 per cent of the recorded gamefishing shark catch at monitored tournaments was shortfin mako (*Isurus oxyrinchus*), followed by tiger (17.4 per cent), whaler (16.7 per cent), hammerhead (13 per cent) and blue sharks (12 per cent). Reported tag-and-release rates for most shark species were similar to those of other species taken (between 80 per cent and 100 per cent) except for tiger sharks with only 29.8 per cent released and the remainder retained for weighing (Murphy et al. 2002). This may be because tiger sharks can be very large and anglers receive high competition points for landing larger specimens. Small tiger sharks are more likely to be tagged and released. High rates of tag-and-release during tournaments reflect their organised nature, the familiarity of competitors with its benefits and the incentive to gain competition points for tagged fish. Tournaments provide an excellent opportunity to examine approaches to handling sharks during tag-and-release and educate anglers on recommended methods of handling.

Table 1. Numbers of shark tagged, weighed and 'not weighed' reported in radio schedules during tournaments monitored from 1996–97 to 1999–2000 fishing seasons (adapted from Appendix 15, Murphy et al. 2002). 'Not weighed' fish are those reported but not counted for competition points.

Common name	Tagged	Weighed	Not weighed	Total
Blue shark	130 (86.7%)	20	0	150
Hammerhead shark	151 (92.6%)	12	0	163
Shortfin mako shark	406 (81.9%)	83	7	496
Tiger shark	64 (29.8%)	151	0	215
Whaler sharks	164 (79.6%)	40	2	206
Sharks-other	2 (100%)	0	0	2
All sharks	**920 (74.4%)**	**306**	**11**	**1237**

The NSW Department of Primary Industries (NSWDPI) has operated a national gamefish tagging program since 1973. Free tagging kits are provided to members of registered angling clubs affiliated with the GFAA or ANSA, as well as charter boat operators. The program operates in 177 angling clubs throughout Australia, with 138 clubs along the east coast. It has provided valuable information to improve the understanding of the distribution and behaviour of shark species in Australian waters. By the end of June 2005, anglers had reported more than 300 000 fish tagged and released under this program (Anon. 2007c). More than 25 000 sharks have been tagged (8.3 per cent of the total). More than 9100 whaler sharks (a group comprising 10 or more species) have been tagged, with approximately 200 recaptures reported. Mako sharks are the most commonly tagged species (5534 tagged with 134 recaptures), followed by blue sharks (3500 tagged with 59 recaptures).

Post-release survival

Little is known of post-release survival associated with catch-and-release or tag-and-release of sharks. It is difficult to evaluate, and regardless of the fishing method, sharks that are caught are exposed to varying degrees of physical and physiological trauma. For example, a shark hooked in the jaw may be played for a longer time on the line than a shark hooked in the stomach, but the relative impacts are not well known. The following section examines approaches that have been used in examining physiological and physical stress.

Physiological impacts

Determining pre-stress levels of physiological indicators is problematic due to lack of controls in experiments. Researchers in this field often assume the blood chemistry of samples taken from fishes that are handled minimally or for the shortest amount of time to be baseline (Skomal and Chase 2002). However, as Skomal (2007) reports, changes in some blood chemistry parameters, like acid-base, are manifested rapidly (within five minutes). Exhaustive exercise and stress, as a result of being hooked and played, causes major metabolic, acid-base and ionic changes in the blood of fish. The majority of swimming activity in fish is aerobic. However, burst-type exercise, such as when a fish is hooked, is largely supported by anaerobic glycolysis within the white muscle. Muscle glycogen is converted to lactic acid. Unlike aerobic activity, anaerobic exercise can only be maintained for short periods of time and results in fatigue (Kieffer, 2000). The majority of studies have focused on tuna and billfish. Tuna and lamnid sharks share a similarity in the internal physiology and morphology of their complex locomotor systems, especially white muscle (Bernal et al. 2004).

By measuring hematologic and blood chemistry values, especially plasma enzymes, physiological changes after exhaustive exercise, including organ dysfunction, can be assessed (Wells et al. 1986). In the case of severe exhaustion, lactates are released into the blood stream from the muscles and may cause metabolic acidosis. The post-capture metabolism of accumulated lactates in the muscles will also lead to an elevated oxygen demand, which must be considered during subsequent transport and handling of the fish (CATAG, 1999). Stress may also lead to an elevation in hormone levels such as cortisol, adrenaline, and noradrenaline in the blood and a reduction in immune responses (Wells et al. 1986). Cortisol then acts to take energy away from the tissue growth, healing, and reproductive processes so that muscles and tissue needed to ‘escape’ are well supplied.

Skomal and Chase (2002) attempted to quantify the physiological consequences of angling stress on large pelagic fish. They sampled blood from 312 fish, including 77 sharks, to examine the impact of high anaerobic muscular exercise due to rod-and-reel angling on blood gases, pH, lactate and cortisol. Preliminary analysis of blood chemistry from 72 blue sharks exhibited significant homeostatic perturbations as a result of exhaustive exercise, characterized by a significant reduction in blood pH, elevated blood lactate and changes in serum electrolyte levels. Blue sharks that were tracked after being tagged and released showed periods of altered behaviour post-recovery. This lasted two hours or less and was characterised by periods of vertical swimming activity. The authors hypothesized that physiological disturbances experienced as a result of exhaustive exercise are corrected during this post-release period, but fish may be vulnerable to predation at this time (Skomal and Chase, 2002). The authors concluded that pelagic gamefish are capable of recovery when handled properly and not subjected to extensive physical trauma.

Similarly, Spargo et al. (2001) took blood samples from 104 juvenile sandbar sharks (*Carcharhinus plumbeus*) to examine changes in blood chemistry after exhaustive exercise from rod-and-reel angling (24 sharks were angled in the field, sampled and released, and another 80 were transported to a holding tank with half allowed to recover and the others angled to exhaustion). The study found blood levels of lactate, glucose, potassium, calcium and magnesium were elevated during stress while pH was reduced. Most metabolites returned to normal levels within 6-10 hours post-release, suggesting juvenile sandbar sharks are able to recover after exhaustive exercise associated with rod-and-reel angling. In addition, five of the released sharks were recaptured up to 12 months later, suggesting long-term survival following exhaustive exercise.

A number of factors may influence the pre- and post-exercise condition of fish (Kieffer, 2000) including:

- body size
- nutrition
- water temperature
- pH
- salinity
- oxygen levels.

In a study carried out by Cliff and Thurman (1984) on transporting dusky sharks (*C. obscurus*), glucose levels were shown to be elevated during stress and low in sharks which did not survive. This suggests that although sharks can recover from a degree of stress there is a level at which they will succumb. This study also found the sharks required a 24-hour recovery period for their blood values to return to pre-stress levels following capture. Skomal (2007) reports that for rod-and-reel caught sandbar sharks, recovery of acid-base blood chemistry to pre-stress levels occurred in less than three hours. Available evidence suggests that high anaerobic activity in sharks causes extreme homeostatic disruptions that may impede normal physiological and behavioural function (Skomal, 2007).

The stress response in fish is not limited to exhaustive exercise. Nearly all physical factors discussed in the following section have a stress component and a post-release recovery period associated with them.

Physical impacts

The various fishing methods used by recreational anglers cause some degree of internal or external trauma. For example, nets can cause external damage from abrasion whereas hooks can cause internal tissue damage or damage to the mouth. According to education material produced by the NSSRLCF, the key survival issues are (*Released Fish Survival Fact Sheet,* Appendix 1):

- playing time
- deep hooking when using baits
- hook damage and leaving hooks in fish
- rough handling.

Other factors affecting post-release survival include:

- species (Musick and Bonfil, 2004)
- depth of capture (more likely to affect fish with a swim bladder rather than sharks)
- temperature
- duration of air exposure
- post-release recovery time (related to post-release predation mortality)
- body size (Casselman, 2005)

Some shark species are noted as being hardier to capture than others. Shark species use one of two methods of respiration. Ram jet ventilation involves constant water flow over the gills by taking in water through the mouth while swimming. It is typical of many streamlined sharks such as white (*Carcharodon carcharias*), mako and whale sharks (*Rhincodon typus*). Many bottom-dwelling species are able to pump water over their gills, often taking in water through a vestigial gill called a spiracle, found just behind the skull on the upper part of the head. Species that employ this method include wobbegong (Orectolobidae) and nurse sharks, as well as skates and rays (Last and Stevens, 1994). This form of breathing may lead to reduced stress in specimens taken from the water, increasing survivability (noting that many species employing ram-jet breathing are large and tagging should take place with the animal in the water).

The factors said to influence the survival of released sharks are not necessarily independent of each other. Some or all of the above factors may compound to affect post-release survival by contributing to stress or lengthened post-release recovery time.

The tagging process generally implies capture and possibly handling, and thus raises the same issues with respect to cryptic mortality as those posed by recreational angling. There is additional risk arising if extra handling, greater time out of water or increased stress is associated with tagging.

Hook impacts

In addition to the physiological effects of exhaustive exercise on fish, fishing gear can cause physical trauma, observed as external and internal tissue and organ damage. Recreational angling typically involves the use of hook and line. The location of the hook in the caught fish is an important factor influencing the degree of physical trauma experienced by the fish and cryptic mortality.

Hooking mortality is usually defined as the number of fish that do not survive beyond a predetermined post-release recovery period (CATAG, 1999). Numerous studies on “deep-hooking” (hooking in the stomach, oesophagus, pharynx or gills) have determined that it leads to higher incidences of angler/tagging induced cryptic mortality especially when vital organs are lacerated or bleeding occurs (Gjernes, 1990, Grover, 1995).

Vestigial hooks may have a sub-lethal impact on sharks, affecting their ability to feed and mate. Borucinska et al. (2001) provided the first scientific reports of systemic debilitating disease associated with fishing hooks retained in a single shark. They found that a hook caused gastric perforation which then led to infection in a blue shark. The body weight of the shark was significantly lower than that determined by the blue shark length-weight relationship suggesting malnutrition as a result of the injury and infection. The study also revealed that 6 of 211 blue sharks landed by recreational anglers had hooks retained. The hooks were embedded in the oesophagus (n=3) causing partial obstruction or in the gastric wall (n=3) causing perforation of the liver (n=2). The resulting lesions included oesophagitis, gastritis, hepatitis and peritonitis. One shark with peritonitis revealed on histological examination the bacteria *Vibrio* sp. and *Aeronomas* sp. Borucinska et al. (2001) report that the body mass of all six sharks examined was within the normal range reported for male blue sharks, suggesting they were not debilitated when recaptured. However, they also reported that active inflammation associated with the hooks and intralesional bacteria were present in each of these sharks, and thus progression of the disease leading to debilitation or death could not be ruled out.

The *Recovery Plan for the Grey Nurse Shark (Carcharias taurus) in Australia* (2002) states that ‘a recent autopsy carried out on a grey nurse shark that died in captivity, the cause of death was attributed to peritonitis arising from perforation of the stomach wall by numerous small hooks of the type used by recreational anglers’ and that ‘hook wounds to grey nurse sharks can puncture the stomach, pericardial cavity, and oesophagus causing infections and death. A hooked shark, upon release, may swim away seemingly unharmed, only to die several days later from internal bleeding or peritonitis’ (DEH, 2002a).

Circle hooks

The NSSRLCF has adopted the term ‘friendly tackle’ and one of the major strategies under this project is to encourage use of such equipment, including circle hooks (Sawynok and Pepperell, 2004). The 2000+ United Kingdom shark tagging program promotes both the use of circle hooks or plain painted hooks to avoid deep hooking, thus reducing the potential for internal damage (Drake et al. 2005).

A large number of studies have compared the effectiveness of circle hooks in reducing post-release mortality. Most studies have compared circle hooks and traditional “J” hooks. Circle hooks represent a major change in hook design potentially providing conservation benefits. However, research on the benefits of circle hooks in reducing deep-hooking in sharks is limited (Ward et al. 2008).

A number of researchers report that circle hooks more frequently hook in the jaw of fish, leading to substantially less gut hooking, resulting in reduced mortality for catch-and-release of tuna, billfish and striped bass (Lukacovic, 1999; Skomal and Chase, 2002; Domeier et al. 2003; Reiss et al. 2003; Cooke and Suski, 2004). However, Cooke and Suski (2004) found that circle hooks were more damaging than J-hooks for some fish species, depending on factors such as mouth morphology, feeding mode, hook size and fishing style.

In summary, many benefits have been found in the use of circle hooks in a range of fish species. However, caution is required as there is limited information available on potential impacts on sharks.

Other hooks

The National Consultative Committee on Animal Welfare (NCCAW) position paper, *Animal Welfare Aspects of Recreational Fishing* (1999) encourages the use of barbless hooks and hooks that rust and break down (DAFF, 2008). The *Code of Best Angling Practice for Sharks in the British Isles* recommends the use of bronze finished hooks (Anon., 2006). This code of practice suggests these hooks dissolve within the mouth within five days. The code also recommends the use of circle hooks and suggests crushing the barbs of hooks to improve survivability.

The US National Marine Fisheries Service’s *Fishery Management Plan for Atlantic Tunas, Swordfish and Sharks* (NOAA, 2003) stipulates the use of non-stainless steel corrodible hooks. Conversely, stainless hooks have been proposed over non-stainless to reduce mortality as they produce less galvanic action (Horst, 2000) and hence reduce infection.

The pamphlet *Gently does it* (Anon. 2007d), produced through the NSSRLCF, states that fish caught on artificial lures are likely to survive better than fish caught on bait because there is less likelihood of fish being deep-hooked when using lures, especially hard bodied lures. Anon. (2007d) also supports the use of artificial lures with barbless hooks because they are easier and quicker to remove and result in less damage when removing hooks. Barbless hooks have been legislated in the Canadian provinces of Manitoba and Alberta for recreational angling (Casselman, 2005).

A telephone survey was conducted in 2004 under the NSSRLCF (Anon. 2004). This was a follow-up to an initial survey conducted in 2002. The 2004 survey found that a total of 81 per cent of respondents agreed that using barbless hooks increased survival rates of fish generally (79 per cent in 2002). Single barbed hooks continued to be the most dominant hook type used in the 2004 survey, with the percentage of respondents using single barbed hooks increasing to 10 per cent from 5 per cent in 2002. Use of multiple hooks may have greater impact on catch mortality due to the longer time for removal or larger capacity to physically damage the animal.

Exposure to air, time out of water

Rough handling, use of gaffs and excessive time out of water can cause irreparable damage to sharks (Skomal and Chase, 2002). The time out of water is related in part to the type of hook used for capture and the time it takes for removal. The process of tagging can further add to the time out of water. Exposure of gills to air causes the gill lamellae to collapse, reducing the ability to exchange oxygen and carbon dioxide. Blood oxygen consequently decreases and carbon dioxide increases (Casselman, 2005). The physiological changes associated with exposure to air are akin to those induced in response to stress.

A study of epaulette sharks (*Hemiscyllium ocellatum*) revealed that this species is capable of tolerating quite high levels of hypoxia (Routley et al. 2002). This may be associated with the fact that they inhabit shallow reef platforms which may be subject to quite high temperatures and associated decreases in dissolved oxygen.

Of those anglers surveyed in the 2004 telephone survey (Anon. 2004), 48 per cent recalled that reducing the time that fish are kept out of the water was a major message of the NSSRLCF. The International Game Fish Association recommends estimating the weight of sharks while still in the water rather than boating them and this approach is used in the NSWDPI Gamefish Tagging Program.

Handling

Rough handling of sharks may contribute to cryptic mortality by physically damaging the animal or contributing to excessive stress. Encouraging best practice in the handling of released fish and overall reduction of recreational released fish mortality have been major goals of the NSSRLCF. Recommendations to this end have been presented through a public awareness campaign (Anon. 2007a). Issues of animal welfare are given high value in Australia and there is abundant literature on best handling practices for catch-and-release, much of which has been produced as a response to the NSSRLCF. A large selection is available on the Infofish website (http://www.info-fish.net/releasefish/) through the *Gently does it* campaign, including one specific to sharks and rays (Appendix 1).

In some respects, sharks require a different approach when handling than that recommended for fish, not the least being to minimise the danger of being bitten. Lifting a shark by the tail may tear internal connective tissues, which are quite loose. Fish should be supported under the belly and not held vertically by the gills. Large sharks should be left in the water (Pepperell, 2005).

Other shark-specific handling recommendations include covering their heads with a wet towel to calm them and giving them a wadded towel to bite on (PSRF, 2008). De-hookers are recommended in many fisheries and are a requirement under the USA’s Fishery Management Plan for Atlantic Tunas, Swordfish, and Sharks (NOAA, 2003).

Play time

Intense and prolonged stress during capture may result in cryptic mortality. Recommendations for the treatment of fish and improved survival of released fish generally advise recreational anglers to use a heavy line in order to bring the fish in quickly thereby minimising stress. A study on bluefin tuna (*Thunnus thynnus*), yellowfin tuna (*Thunnus albacares*) and blue sharks (Skomal and Chase, 2002) found that these species were capable of recovery when not subjected to extensive physical trauma. Blood chemistry data from tagged and released animals indicated the level of stress was commensurate with play time. Reducing play time reduced the extent of change to blood chemistry and potentially reduced the vulnerability of fish to predation during recovery from stress (Skomal and Chase, 2002).

Species

Handling or tagging induced cryptic mortality will depend on the shark’s morphological attributes, life history, behaviour and habitat (Musick and Bonfil, 2004). There is no single tag suitable for all species of shark. The sub-lethal effects of tagging on survival, reproduction, and growth should be taken into account for tagging programs for a given species.

Although not related to recreational angling, observer data from capture of sharks on pelagic longlines has shown variation across species in the percentage retrieved in an alive and vigorous condition. Ward and Curran (2004) report dusky sharks (~ 90 per cent) and blue sharks (~70 per cent) to be frequently alive and vigorous, with this condition less common for mako (55 per cent) and thresher sharks (30 per cent).

Tagging programs

When investigating tag-and-release induced cryptic mortality, it is difficult to determine whether the tag itself has caused death or the tagging process (including capture, boating and release). Lipsky and DeAltaris (1999) comment that experiments have shown that mortality, as an immediate and direct result of tagging is virtually non-existent, referring to the actual attachment of the tag and not the actual capture and tagging process, that can sometimes be prolonged.

Tag type may influence cryptic mortality. There is evidence that gastrically-inserted transmitters contribute to lower cryptic tag mortality than externally attached or surgically implanted electronic tags (CATAG, 1999). Bleeding and tag position have been discussed previously in this report as factors influencing cryptic mortality and may also be a function of tag type. No specific studies on these issues were found.

In scientific tagging studies, often only the most vigorous and healthy specimens captured are tagged and released. This is unlikely to be the case for recreational anglers. Consequently, cryptic mortality associated with the tagging process may vary widely as a result of inconsistencies in the selection of specimens for tagging.

Sub-lethal effects

The sub-lethal effects of gamefishing and tagging are poorly quantified, especially for sharks. The sub-lethal effects of tagging and release without tagging have been recognised as needing further investigation in the *White Shark (Carcharodon carcharias) Recovery Plan* (2002) (DEH, 2002b).

Many of the factors covered in this report which are said to influence cryptic mortality may also have sub-lethal effects. Noting that many of these apply in catch-and-release, whether the fish is tagged or not, factors include:

- retained hooks, hook damage and tags which may affect feeding, growth, reproduction and movement
- stress response and physiological changes, influenced by playing time, handling, time out of water, tagging and ambient temperature.

A number of techniques can be used to assess the post-release behaviour of fish including use of water tanks or observation in small or isolated fisheries (Reiss et al. 2003). Although these techniques are mostly not practical for studying most shark species due to their large size and difficulty in handling, experiments are in progress in Australia to monitor the physiology of captive gummy sharks (TI Walker, pers. comm).

A variety of tagging methods including ultrasonic telemetry (Gurshin and Szedlmayer, 2004), (Holts and Bedford, 1993; Holland et al. 1999; Skomal and Chase, 2002) and satellite tags (CSIRO, 2001) have been used to assess the post-release behaviour of shark and hence infer survival rates.

Short term post-release survival in several studies has been found to be high, ranging from 100 per cent survival for shortfin mako sharks (Holts and Bedford, 1993) and tiger sharks (Holland et al. 1999) to 90 per cent survival for Atlantic sharpnose shark (*Rhizoprionodon terraenovae*) (Gurshin and Szedlmayer, 2004). Post-release behaviour was characterized by significantly higher rates of movement after release, followed by periods of slower movement in Atlantic sharpnose sharks (Gurshin and Szedlmayer, 2004) and shortfin mako sharks (Holts and Bedford, 1993). This behaviour was not observed in tiger sharks (Holland et al. 1999). These observations are consistent with reports that the physiological response to exhaustive exercise in fish differs between species. Possible impacts of changes in long-term post-release behaviour on inter- and intra-species interactions have not been resolved for any fish species due to its extreme complexity.

There is very little research into the post-recovery period required by sharks after capture and tagging. As has been found for fish, sharks may be susceptible to predation during this period (cryptic predation mortality). The recovery period for sharks exhibiting physiological changes associated with stress have been found to be two hours for blue sharks (Skomal and Chase, 2002) and less than three hours for juvenile sandbar sharks (Spargo et al. 2001). No studies have been published on mortality caused by physical damage to sharks other than for surface wounds (Heupel and Bennet, 1997).

Post release survival factors

The following factors associated with tagging influence cryptic mortality after sharks are released.

Soak time

Soak time is a factor in the survival of captured shark (Musick and Bonfil, 2004), though this is predominantly relevant to scientific tagging and commercial fishing. Variation in the survival of shark species in this instance may be related to the respiratory method and other morphological attributes.

Tag type, attachment and placement

All tagging has impacts on the health of the animal in some way, by either breaching skin and musculature with a tag applicator or involving surgery (CATAG, 1999). There are numerous types and versions of tags, with many researchers modifying the tag to suit their purposes.

Little is known about the effects of tags on sharks, and research into surface wounds and healing in sharks is limited. Heupel and Bennet (1997) examined tissue samples from the tag insertion site of 55 epaulette sharks (*Hemiscyllium ocellatum*) that had been tagged using conventional external dart tags. The authors found that the wounds from tagging healed rapidly, there were no signs of infection and recaptured sharks remained healthy. They concluded that there was no reason to believe that tagging would increase the mortality of this species.

Heupel et al. (1998) examined tissue response in Australian requiem sharks (carcharhinids) tagged with Jumbo Rototags (cattle ear tags). They found erosion of the dorsal fin surface when the tags had been attached too tightly. Organisms such as bryozoans and poriferans were growing on the tags and caused abrasion of the fin surface. Despite these observations, the authors found the tags to be an efficient means of tagging sharks without causing extensive damage or trauma. Further research was recommended into the effects of temperature, habitat and age of the shark on tissue response (Heupel et al. 1998).

Estimated tag shedding rates are important in estimating the cryptic mortality associated with tagging. Tag shedding rates will depend on tag type, tag position, tagging procedure and species. Factors such as tag attachment methods and materials, tag shape and coating, suturing material, pre- and post-operative care and confinement should be given attention as these factors will influence post-release behaviour and mortality. The post-release perturbation period should be identified in the feasibility study for tagging projects (CATAG, 1999).

Current research

Increased focus on the sustainability of sharks, as well as the profile given to recreational angling through various media has seen an increase in research being undertaken into the impacts of recreational angling and catch-and-release. The NSSRLCF has supported important research to improve the survival of line-caught fish and state and territory governments have a strong focus on recreational angling research.

A number of dive clubs and organisations are contributing to the visual survey of Australian shark colonies. For example the Underwater Research Group Dive Club of NSW regularly surveys grey nurse colonies at Magic Point Maroubra and Long Reef as part of a larger NSW Fisheries initiative (http://www.urgdiveclub.org.au). The Scuba Clubs Association of NSW (SCAN) is also actively involved in monitoring NSW grey nurse colonies. The Australian Underwater Federation has been funded through a Commonwealth Government initiative for the Great Australian Shark Count, focussed on collating information on sightings by divers. The project reports over 7500 shark sightings as of September 2008 (http://www.auf-spearfishing.com.au/).

Stationary underwater acoustic receivers (listening stations) in conjunction with external acoustic transmitter tags (telemetry) have been used with success in certain shark habitats to provide valuable information on shark movements. Recent Australian (CSIRO) studies have used acoustic transmitter tags and listening stations to track movements of white sharks and deep water sharks.

Despite the increased focus on the need for conservation of sharks and rays in Australia and overseas following initiatives such as the IPOA-Sharks, the need for improved information continues to be a high priority. Several projects are in progress to improve the level of biological information on sharks and extend understanding of the interaction between commercial fisheries and sharks. However, there is a lack of information on the impacts of recreational fishing on sharks and rays and few of the current projects underway in Australia are looking at this. Increased efforts are required to improve understanding of these important species. Along with traditional approaches, improved technology in tagging holds prospects to greatly increase the knowledge of shark and ray behaviour as it becomes cheaper and more widely available. The key hurdle is for research into shark survival to be given high priority and adequate funding support.

Conclusions

Many species of sharks, rays and skates are at risk from fishing in Australia and overseas. They are difficult to study and the diversity of species found in Australia makes it difficult to implement general mitigation measures. The recreational catch of sharks in Australia is significant, with most of those sharks released. Total catch levels and survival rates of released sharks are highly uncertain. Information on tag-and-release mortality for various fish species is expanding, but there is little material specific to sharks. Most information that is available relates to scientific tagging or to commercial fisheries. National educations programs on release techniques have not focused on sharks.

The limited studies of post-release survival indicate that survival rates of released sharks often exceed 90 per cent. Survival rates of sharks released by anglers are likely to be more variable and lower than those estimates because anglers release them regardless of the shark's physical condition. Anglers can improve the survival of released sharks through using heavier lines (which reduce play times), hastening release, removing hooks, using appropriate handling techniques and not removing the shark from the water. The use of lures (in place of baited hooks), dissolving hooks and barbless hooks also improve shark survival rates. Circle hooks have been shown to improve the survival of many fish species because they often lodge in the jaw. The benefits of circle hooks for sharks require investigation.

To improve survival rates and maximise the benefits of tag-and-release, research is required into tagging and handling techniques as well as education of industry and recreational fishers. As it becomes cheaper and more reliable, improved technology in tagging holds the prospect to increase the knowledge of shark and ray behaviour. In particular, pop-up satellite tags will provide information on the behaviour and survival of released sharks. Difficulties will remain in obtaining reliable estimates of survival rates because of variations among species, body-size, ambient conditions, play times and handling practices among anglers. Nevertheless, those studies will provide guidance on the benefits of releasing sharks and advice on ways of improving the chances of released animals surviving. Conventional tagging programs could also be used to quantify the benefits of different tagging and release techniques. For example, analyses of recaptures where a shark species is tagged and released under different treatments (e.g. with and without the hook removed) would provide guidance on the merits of those release techniques.

References

Anon., 1991. School shark recaptured 42 years after tagging. Australian Fisheries, May 1991, p.5.

Anon., 2004. Released Fish Survival National Follow Up Survey Report. National Strategy for the Survival of Released Line-caught Fish. Prepared by for *Infofish* Roy Morgan Research, web address — http://www.info-fish.net/releasefish/ (as at June 2008).

Anon. 2006. Code of Best Angling Practice for Sharks in the British Isles, National Oceanography Centre, Southampton, web address — http://www.soc.soton.ac.uk/ukshark/ (as at June 2008).

Anon., 2007a. National Strategy for the Survival of Released Line-caught Fish 2006, Edition 10. Fisheries Research and Development Corporation and *Infofish*, web address — http://www.info-fish.net/releasefish/ (as at June 2008).

Anon., 2007b. Releasing sharks, rays and sawfish – fact sheet. Queensland Government Environmental Protection Agency, web address — http://www.epa.qld.gov.au/publications/p02176aa.pdf/Releasing_sharks_rays_and_sawfish.pdf (as at June 2008).

Anon., 2007c. NSW DPI Game Fish Tagging Program—Summary and Report to July 2005. New South Wales Department of Primary Industries.

Anon., 2007d. Gently does it; a guide for releasing fish to survive, *Released Fish Survival* pamphlet. Fisheries Research and Development Corporation and *Infofish*, web address — http://www.info-fish.net/releasefish/ (as at June 2008).

ANSA, 2008. Web address — http://www.ansa.com.au/, as at June 2008).

Bernal D, Dickson KA, Shadwick RE, Graham JB, 2004. Analysis of the evolutionary convergence for high performance swimming in lamnid sharks and tunas. Journal Article, Nature, May 6, 2004.

Borucinska, J, Martin, J and Skomal, G, 2001. Peritonitis and Pericarditis Associated with Gastric Perforation by a Retained *Fishing Hook in a Blue Shark*. Journal of Aquatic Animal Health 13: 347-354.

CATAG 1999. Improvements of Tagging Methods for Stock Assessment and Research in Fisheries. Marine Research Institute, Reykjavik, Iceland. (http://www.hafro.is)

Cliff, G and Thurman, GD, 1984. Pathological and physiological effects of stress during capture and transport in the juvenile dusky shark, *Carcharhinus obscurus*. Comparative Biochemistry and Physiology 78A: 167-173.

Cooke, SJ, Schreer, JF and Philipp, DP, 1999. Quantifying Sub-lethal Effects of Marine Catch-and-Release Angling – Insight from Novel Freshwater Applications, in Catch and release in marine recreational fisheries: proceedings of the symposium, National Symposium on Catch and Release in Marine Recreational Fisheries, Virginia, USA, 5-8 December (Jon A. Lucy and Anne L. Studholme, eds).

Cooke, SJ and Suski, CD, 2004. Are circle hooks an effective tool for conserving marine and freshwater recreational catch-and-release fisheries? Case Studies and Reviews**,** Aquatic Conservation: Marine and Freshwater Ecosystems, Volume 14, Issue 3, Pages: 299-326.

Cryptic Mortality and Its Effects, Florida Fish and Wildlife Conservation Commission (FFWCC), Fish and Wildlife Institute, web feature, web address — http://research.myfwc.com/features/view_article.asp?id=25021 (as at June 2008).

CSIRO, 2001. Telling shark stories with tags. Fact Sheet no. 41. CSIRO Marine Research, web address — http://www.marine.csiro.au/LeafletsFolder/pdfsheets/41.pdf (as at June 2008).

DAFF, 1994. The National Recreational Fishing Policy. National Steering Committee on Recreational Fishing, web address — http://www.daff.gov.au/fisheries/recreational/policy (as at June 2008).

DAFF, 2006. Recreational fishing community grants program-fish tagging guidelines, Australian Government Department of Agriculture Fisheries and Forestry Australia, Canberra, web address — http://www.affa.gov.au/corporate_docs/publications/pdf/fisheries/RFCGP Tagging_Guidelines.pdf (as at June 2008).

DEH, 2002a. *Recovery Plan for the Grey Nurse Shark (*Carcharias taurus*) in Australia.* Australian Government Department of Environment and Heritage Canberra, web address — http://www.environment.gov.au/coasts/publications/grey-nurse-plan/ (as at June 2008).

DEH, 2002b. Australian Government Department of Environment and Heritage, 2002. *White Shark (Carcharodon carcharias) Recovery Plan.* Canberra, web address — http://www.environment.gov.au/coasts/publications/gwshark-plan/ (as at June 2008).

DEH, 2005. Australian Government Department of the Environment and Heritage 2005. Whale Shark (*Rhincodon typus*) Issues Paper, Canberra.

Domeier, ML, Dewar, H and Nasby-Lucas, N, 2003. Mortality rate of striped marlin (*Tetrapturas audax*) caught with recreational tackle. Marine and Freshwater Research 54**,** 435-445.

Drake, SC, Drake, JA and Johnson, ML, 2005. 2000+ UK Shark Tagging Program: An Angler Led Shark-tagging Initiative in UK Coastal Waters. J. Northw. Atl. Fish. Sci., 35: 233–238.

FAO, 1995. Code of Conduct for Responsible Fisheries, Food and Agricultural Organisation, Rome, web address — http://www.fao.org/documents/show_cdr.asp?url_file=/DOCREP/005/v9878e/v9878e00.htm (as at June 2008).

FAO, 1999. The International Plan of Action for the Conservation and Management of Sharks, Food and Agricultural Organisation, Rome, web address — http://www.fao.org/fi/ipa/manage1.asp (as at June 2008).

Gjernes, T, 1990. Hooking mortality rates for sport caught Chinook and soho salmon. Dep. Fish. Oceans Canada Pacific Biological Laboratory Pacific Stock Assessment Review Committee Working Paper S90-35.

Grover, A, 1995. Evaluation of hook mortality in the California ocean salmon fisheries, 1994 and 1995. California Department of Fish and Game, Marine Resources Division, Healdsburg, USA.

Gurshin, CWD and Szedlmayer, ST, 2004. Short-term survival and movements of Atlantic sharpnose sharks captured by hook-and-line in the north-east Gulf of Mexico. Journal of Fish Biology 65, 973-986.

Henry, GW and Lyle, JM (eds), 2003. The National Recreational and Indigenous Fishing Survey, New South Wales Fisheries, Cronulla, web address — http://www.daff.gov.au/recfishsurvey (as at June 2008).

Heupel, MR and Bennet, MB, 1997. Histology of dart tag insertion sites in the epaulette shark. Journal of Fish Biology 50, 1034-1041.

Heupel, MR, Simpfendorfer, CA and Bennett, MB, 1998. Analysis of tissue responses to fin tagging in Australian carcharhinids. Journal of Fish Biology 52, 610-620.

Holland, KN, Wetherbee, BM, Lowe, CG and Meyer, CG, 1999. Movements of tiger sharks *(Galeocerdo cuvier*) in coastal Hawaiian waters. Marine Biology 134, 665-673.

Holts, DB and Bedford, DW, 1993. Horizontal and Vertical Movements of the Shortfin Mako Shark, *Isurus oxyrinchus*, in the Southern California Bight. Australian Journal of Marine and Freshwater Research. 44, 901-909.

Horst, J, 2000. Releasing your catch. Sea Grant. Louisiana state University, web address — http://www.seagrantfish.lsu.edu/pdfs/factsheets/releasecatch.pdf (as at June

Kieffer, JD, 2000. Limits to exhaustive exercise in fish. Comparative Biochemistry and Physiology Part A 126, 161-179.

Last, PR and Stevens, JD, 1994. Sharks and Rays of Australia. CSIRO.

Lipsky, C and De Alteris, J, 1999. Sensitivity of a Fish Tag-recapture Model to Uncertainty in Tag Loss and Hooking Mortality, in Catch and release in marine recreational fisheries: proceedings of the National Symposium on Catch and Release in Marine Recreational Fisheries, Virginia, USA, 5-8, edited by JA Lucy and AL Studholme.

Lukacovic, R, 1999. Hook Location, Fish Size, and Season as factors Influencing Catch-and-Release Mortality of Striped Bass Caught with Bait in Chesapeake Bay, In Catch and release in marine recreational fisheries: proceedings of the symposium, National Symposium on Catch and Release in Marine Recreational Fisheries, Virginia, USA, 5-8 (Jon A. Lucy and Anne L. Studholme eds).

Manire, CA and Gruber, SH, 1991. The effect of M-type dart tags on field growth of juvenile lemon sharks. Trans. Amer. Fish. Soc. 120(6): 776-780.

Murphy, JJ, Lowry, MB, Henry, GW and Chapman, D, 2002. Gamefishing tournament monitoring program-1993 to 2000. NSW Fisheries Final Report Series, 38.

Musick, John. A and Bonfil, Ramon (Eds), 2004. Elasmobranch Fisheries Management Techniques. IUCN Shark Specialist Working Group.

NOAA 2003. Fishery management plan for Atlantic tunas, swordfish and sharks. Highly Migratory Species Management Division, NOAA Office of Sustainable Fisheries, web address — http://www.nmfs.noaa.gov/sfa/hms/hmsdocument_files/FMPs.htm (as at June 2008).

Pepperell, JG, 2005. Release of Sharks in Recreational Fisheries. Seaweek publication, web address — http://www.info-fish.net/releasefish (as at June 2008).

PSRF, 2008. Pelagic Shark Research Foundation, Santa Cruz, USA, , web address — http://www.pelagic.org/research/BLU_methods.html (as at June 2008).

Reiss, P, Reiss, M and Reiss, J, 2003. *Catch and Release Fishing Effectiveness and Mortality*, web address — *(*http://www.acuteangling.com/Reference/C&RMortality.html (as at June 2008).

Rose, C, 2001. Australian Shark Assessment Report for the Australian National Plan of Action for the Conservation and Management of Sharks (prepared by Cassandra Rose and the Shark Advisory Group). Department of Agriculture, Fisheries and Forestry, Canberra, web address — http://www.daff.gov.au (as at June 2008).

Routley, MH, Nilsson, GE and Renshaw, GM, 2002. Exposure to hypoxia primes the respiratory and metabolic responses of the epaulette shark to progressive hypoxia. Comparative Biochemistry and Physiology Part A. 131:313-321.

SAG, 2004. Australian National Plan of Action for the Conservation and Management of Sharks, (prepared by the Shark Advisory Group). Department of Agriculture, Fisheries and Forestry, Canberra, web address — http://www.daff.gov.au (as at June 2008).

Sawynok, W and Pepperell, J, 2004. National Strategy for the Survival of Released Line-caught Fish - Planning, Project Management and Communications Fisheries Research and Development Corporation and *Infofish*, web address — (http://www.info-fish.net/releasefish/ (as at June 2008).

Skomal, G and Chase, B, 2002. The Physiological Effects of Angling on Post-Release Survivorship in Tunas, Sharks, and Marlin. American Fisheries Society Symposium 30: 135-138.

Skomal, G B, 2007. Evaluating the physiological and physical consequences of capture on post-release survivorship in large pelagic fishes. Fisheries Management and Ecology 14:81-89.

Spargo, AL, Kohler, N, Skomal, G and Goodwin, R, 2001. The physiological effects of angling on post-release survivorship in juvenile sandbar sharks (*Carcharhinus plumbeus*). Abstracts from the American Elasmobranch Society 2001 Annual Meeting.

Symons, R, 1999. Blues in the summer time, web address — http://www.fishing.co.uk/article.php3?id=159 (as at June 2008).

Ward, P and Curran, D, 2004. Scientific Monitoring of Longline Fishing off Western Australia. Bureau of Rural Sciences, Canberra.

Ward, P, Epe. S, Kreutz, D, Lawrence, E, Robins, C and Sands, A. 2008. Implementation of bycatch mitigation measures in Australia's pelagic longline fisheries: the effects of circle hooks on target and non-target catches. Final Report to the Natural Heritage Trust. Bureau of Rural Sciences, Canberra.

Wells, RMG, McIntyre, RH, Morgan, AK, and Davie, PS, 1986. Physiological stress responses in big gamefish after capture: observations on plasma chemistry and blood factors. Comp. Biochem. Physiol. 84A(3): 565-571.

Appendix 1. Released Fish Survival Fact Sheet

Released Fish SURVIVAL

RELEASED FISH SURVIVAL FACT SHEET

SPECIES

Sharks (Several families)
Rays (Several families)

KNOWLEDGE RATING

☑☑☑

5 ticks if there is sufficient knowledge of fish released, survival rates and best practices for the species

BEST PRACTICES IN RELEASING SHARKS AND RAYS

Recommended practices for Sharks/Rays being released:

- Avoid long playing times
- For bait fishing use hooks that reduce gut hooking eg circle hooks
- Release all Sharks or Rays while in the water by removing hooks with pliers or cutting line
- Small Sharks (up to 10kg) may be removed with extreme care from the water (if docile) by lifting by the tail wrist while holding firmly under the body near the pectoral fin with the other hand - if in doubt do not attempt to remove from the water
- Keep tension on line at all times while retrieving to minimise sharks rolling and becoming entangled in the line

Go to reference material in brackets for access to more information on any particular aspect of best practices

Other tips

- Care must be taken when handling Sharks due to the razor sharp teeth and powerful jaws of most species – if in doubt do not remove from the water and cut the line
- With Rays care must be taken to avoid the tail as most Rays have a poisonous barb that can inflict a severe wound - if in doubt do not remove from the water and cut the line
- Both Sharks and Rays have a sandpaper texture skin that can cause abrasions if poorly handled
- Care must also be taken when handling Port Jackson Sharks, Elephantfish and some Dogfish to avoid the strong sharp spines at the front of their dorsal fins

KEY SURVIVAL ISSUES

The following are the most likely survival issues for Sharks and Rays:

- Playing time
- Deep hooking when using baits
- Hook damage and leaving hooks in fish
- Rough handling

Australian Government
Fisheries Research and Development Corporation
RECFISH AUSTRALIA
infofish
Last Updated 1 March 2007

Released Fish SURVIVAL

RECREATIONAL CATCH

Location	Year	Harvest	Released	Catch	% Rel	Ref
National	2000	228,000	1,024,000	1,252,000	81.8%	(1)

Numbers of fish harvested and released in key fisheries with available data

SURVIVAL RATES

No research is currently available on survival rates of released Sharks or Rays.

HOOKING LOCATIONS

No data is currently available on locations where hooks are lodged in Sharks or Rays. It is recommended that gear that reduces deep hooking of Sharks or Rays be used.

REFERENCE MATERIAL

The following reference material has been used in the compilation of this fact sheet and can be used to obtain more detailed information.

(1) Henry G and Lyle J (ed) (2003): The National Recreational and indigenous Fishing Survey: available at www.affa.gov.au/recfishsurvey

This fact sheet is based on the latest available data and will be updated when new information becomes available

Australian Government
Fisheries Research and Development Corporation

RECFISH AUSTRALIA

infofish

Appendix 2. Releasing Sharks, Rays and Sawfish

Threatened Species Week 2007

Releasing sharks, rays and sawfish

FACT SHEET

To raise awareness about how people can help our aquatic wildlife, this year's theme for Threatened Species Week is *'Get off our backs!'* Queensland's aquatic and coastal species are baring the brunt of our ever expanding use of oceans and water bodies.

© EPA, image by George Aldridge

Although many people do care about wildlife, it seems that the message isn't reaching everyone. The careless use of our oceans, beaches and waterways has a direct impact on many threatened species. However, slight changes in human behaviour can make a real difference to threatened species.

Fishing for sharks & rays

Queensland has some of the best fishing in the world. Fishers can enjoy perfect weather and a huge variety of fish in the rich tropical and sub-tropical waters. But despite this abundance of marine life human activities such as development, destruction of habitats and fishing is causing some sharks, rays and sawfish to become threatened.

Sharks

There are a number of unique fish in the waters off Queensland. Among them is the grey nurse shark, which is one of Australia's most threatened marine species. There are only an estimated 500 left from southern Queensland to New South Wales. Although grey nurse sharks are now protected under Queensland law (listed as Endangered), activities such as fishing still have an impact and the survival of the few remaining individuals is critical for the future of this species. Great white sharks have a fearsome reputation, but are also an important predator that helps to regulate the populations of other marine life. Because they are a top-predator, they usually occur at low densities. And as they only reproduce every one to three years, their populations have declined through human impacts.

Estuary stingray © Peter Kyne

Queensland Government
Environmental Protection Agency

Speartooth sharks are restricted to the Gulf of Carpentaria. They are sometimes confused with bull sharks. However, speartooth sharks can be distinguished by spear-like teeth on the bottom jaw that help them to catch fish in the murky rivers in which they feed.

Stingrays

Of the large variety of rays in Queensland's water, the estuary stingray was found to be one of the most threatened by the 'Back on Track species prioritisation framework'. Estuary stingrays occur sporadically all along Queensland's coast where they favour shallow inshore waters, but also live in mangrove-fringed rivers and estuaries. They are threatened by fishing where caught stingrays are killed. Some fishers cut off the tails of stingrays because they are concerned about getting stung, but stingrays often die as a result.

Sawfish

The freshwater sawfish, dwarf sawfish and green sawfish are all of conservation concern. Their saw-shaped rostrum (snout) has electroreceptors which can detect the heartbeats, and movement, of crabs and shrimp buried in the muddy seafloor or river bottom.

Caught and killed

Killing animals caught by fishing does not allow them to breed and restock the population. Landing a threatened shark or sawfish as a trophy, or cutting off the tail of an estuary stingray, removes them from already small populations.

Without those threatened sharks, rays and sawfish in the water and breeding, they will not be around for future fishers.

How can I help?

You can make a difference by releasing caught sharks, rays and sawfish.

- ***If you have a stingray or sawfish on the line*** cut off the trace/line and set it free. The barbed tail of stingrays, and the jagged rostrum of sawfish, makes them too dangerous to handle.
- ***If you have a shark on the line***:
  - ***Take care of yourself.*** Only attempt to lift a shark onboard a boat if it is smaller then 1.3 metres. If it is longer then 1.3 metres, cut off the trace/line and set it free. If you do attempt to lift in onboard, use a wet towel to protect yourself and the animal. Lifting large sharks can cause internal damage to the shark. At all times make sure all your body parts are well away from a shark's mouth. Check that any bystanders are standing well back.
  - ***Take care of the animal.*** Avoid long playing times, as they are not needed to bring a shark in. If you do attempt to lift it onboard, lift by the tail wrist, using the other hand to support the animal under the body near the pectoral fin. When holding a shark onboard, hold it down behind the first and second dorsal fins to stop your hands slipping towards the mouth. Don't put too much pressure on the animal, as that can squash the internal organs.
  - ***Take the hook out.*** If your hook has a barb, use bolt-cutters to remove the barb, and then pliers or a hook-removing device to remove the hook.
  - ***Take the animal back to the water.*** Release the animal back into the water as soon as possible.
- ***Use non-stainless steel hooks*** that rust and drop off if the trace/line is cut. Stainless steel hooks do not rust and cause continuous injuries for the animal and other marine life.

For further information:

Best practices in releasing sharks and rays (http://www.info-fish.net/releasefish/files/397/Releasing Shark and Ray.pdf), from Infofish.

Shark fishing – safety first (http://www.dpi.qld.gov.au/cps/rde/xchg/dpi/hs.xsl/28_3140_ENA_HTML.htm), from the Department of Primary Industry and Fisheries.

How to release fish for survival (http://www2.dpi.qld.gov.au/fishweb/13049.html), from the Department of Primary Industry and Fisheries.

Looking after protected species in Queensland: A guide for recreational anglers (http://www2.dpi.qld.gov.au/extra/pdf/fishweb/recprotectedspecies.pdf), from the Department of Primary Industry and Fisheries.

Don't get hooked on stainless steel, from the Environmental Protection Agency (http://www.epa.qld.gov.au/).

Grey nurse shark fact sheet, from the Environmental Protection Agency.

Estuary stingray fact sheet, from the Environmental Protection Agency.