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Hunting cetaceans with sound: a worldwide review

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ABSTRACT

Cetaceans are sensitive to a variety of anthropogenic sounds because they normally use sound to navigate, communicate and capture prey. This paper reviews some fisheries that have taken advantage of this sensitivity by using sound to help capture numerous species of dolphins and whales. Fishermen in many parts of the world have independently developed methods that use sounds to drive (herd) various species of small cetaceans so that they can be killed and used for food, culled (i.e. to offset competition for fish), help capture fish (e.g. in the Eastern Tropical Pacific) or be taken into captivity. It is well documented that drive fisheries for small cetaceans have occurred for at least 650 years in Japan and Europe. With respect to large whales, the use of sound became widespread after World War II, with the advent of an early form of sonar (ASDIC) which was used for hunting both baleen and sperm whales. Baleen whales displayed a strong avoidance reaction to ASDIC by swimming rapidly away from the sound while remaining near the surface of the water. In contrast, sperm whales made longer dives in response to ASDIC. During the 20th Century, fishermen using these two acoustical methods killed millions of cetaceans (including those caught in the Eastern Tropical Pacific tuna fisheries), both small and large. The effectiveness of acoustic capture methods shows that a wide range of cetacean species have strong avoidance reactions to a variety of anthropogenic sounds. Research to better document the characteristics of these sounds, including those used in existing drive fisheries and those produced by ASDIC devices, would improve understanding of the types of anthropogenic sounds that could contribute to mass-stranding events and should be minimised in protected habitats for cetaceans.

KEYWORDS: SMALL CETACEANS; SONAR; STRESS; HEARING; DIRECT CAPTURE; LIVE-CAPTURE; WHALING-HISTORICAL; WHALING-MODERN; WHALING-SMALL TYPE; ACOUSTICS; SPERM WHALE; STRIPED DOLPHIN; SHORT-FINNED PILOT WHALE; FALSE KILLER WHALE; RISSO'S DOLPHIN; PANTROPICAL DOLPHIN; PYGMY KILLER WHALE; MELON-HEADED WHALE; KILLER WHALE; FRASER'S DOLPHIN; HARBOUR PORPOISE; LONG-FINNED PILOT WHALE; ATLANTIC WHITE-SIDED DOLPHIN; NORTHERN BOTTLENOSE WHALE; PACIFIC WHITE-SIDED DOLPHIN; GRAY WHALE; BLUE WHALE; HUMPBACK WHALE

INTRODUCTION

Cetaceans depend on sound and hearing to a greater extent than most terrestrial mammals. Many odontocetes produce high-frequency sounds and use echoes from these sounds to navigate and help capture prey (e.g. Au, 1993; 2002). Odontocetes also produce lower frequency sounds to communicate with each other (Caldwell and Caldwell, 1965; Sayigh *et al*., 1990) and baleen whales produce very low frequency sounds (Watkins *et al*., 1987) that can propagate over extremely long distances. Given the natural importance of sound in the life of cetaceans, it is not surprising that they are sensitive to a variety of anthropogenic sounds. Humans have taken advantage of this sensitivity by using artificial sounds to assist in capturing a variety of cetacean species in many parts of the world. Two general types of sound have been used to help capture cetaceans: a variety of 'low-tech' sounds used to help drive small cetaceans into shallow bays or nets or make them strand; and more sophisticated sonar-related devices (ASDIC) used to track or scare large whales.

There are numerous reports (e.g. Mitchell, 1975a) of fishing operations that have developed methods to herd or drive small cetaceans to shore. Although occasionally the noise from boat engines appears to be the only acoustic component used in these fisheries, in most cases the fishermen have developed deliberate methods of producing underwater sound. This sound acts as an acoustic 'curtain' that the fishermen use to herd the small cetaceans into a harbour or bay where they can be killed or taken into captivity. After sonar (ASDIC) was developed in World War II, it was used to assist with commercial whaling operations for sperm (*Physeter macrocephalus*) and baleen whales.

Ambient noise levels in the deep ocean have been increasing in recent decades due to anthropogenic sources (McDonald *et al*., 2006), as has interest in the ways in which anthropogenic sound may affect cetacean populations. However, recent reports (e.g. NRC, 2005) have not documented the behavioural responses of cetaceans to sounds used to help catch them and therefore it is timely to review the various fisheries that have used sound to help capture both odontocetes and baleen whales. An increased awareness of the responses of cetaceans to these sounds could be useful in assessing the environmental impacts of other anthropogenic sounds.

METHODS AND MATERIALS

Previous reviews (e.g. Mitchell, 1975a) of drive fisheries for small cetaceans have been updated with more recent information when available, but the purpose of this paper is not to describe these fisheries in detail. However, the operation of each fishery is explained as far as possible, especially the methods and sounds used. Information is also provided on the use of sonar (ASDIC) in commercial hunting of large whales.

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RESULTS

Drive fisheries for small cetaceans

Mitchell (1975a) described the general methods used to kill or capture small cetaceans around the world. One such fishery is the 'drive fishery' or 'drive method'. Mitchell (1975a) noted that

> 'in this type of fishery the animals are manoeuvred into a confining situation where they are either entrapped or immediately driven ashore and killed. Driving is usually accomplished with a number of small boats, which are used to herd the animals. In many cases, special efforts are made to generate noise, which aids both in containing the school and in hastening its movements'.

The best-documented cases of fishermen using sound to help drive and catch large numbers of small cetaceans are the dolphin fisheries in Japan, Taiwan, the Solomon Islands, the Faroe Islands, the Eastern Tropical Pacific and Newfoundland, Canada. The fishery in the Eastern Tropical Pacific differs from the others, in that the primary target of the fishery is tuna rather than dolphins. Each of these fisheries is described briefly below to illustrate the broad range of species hunted with the help of sound and the worldwide occurrence of this fishing method. More detailed accounts can be found in the references cited under each fishery.

Japan

Since the 14th Century, at least 52 Japanese villages have operated small-cetacean drive fisheries, although the number of villages involved has declined over time. By 1982, when a license system for the fishery was initiated, only four villages registered (Kasuya, 2002). During the 19th Century and the first half of the 20th Century, the main species hunted was the striped dolphin (*Stenella coeruleoabla*) but now the fishery focuses mainly on other species: short-finned pilot whales (*Globicephala macrorhynchus*); false killer whales (*Pseudorca crassidens*); Risso's dolphins (*Grampus griseus*); and pantropical dolphins (*Stenella attenuata*) (see review by Bjørge *et al*., 1994; Kishiro and Kasuya, 1993; Ohsumi, 1972). Methods used in the early years of the fishery are unknown. During the 19th and early 20th Centuries, the fishery operated at a minimum of six sites: in the Sea of Japan, the East China Sea, and several places along the Pacific coast influenced by the warm Kuroshiro Current (Kishiro and Kasuya, 1993), capturing a variety of warm-temperate and tropical species of small cetaceans. Since fishermen started to use boats with motors, they have opportunistically hunted dolphins by herding them toward shore when sighted in coastal waters. These methods are described in detail by Ohsumi (1972). Scouting boats routinely search for dolphins as far as 30-40 miles offshore. When a scouting boat finds a school, it reports to the office on shore and 10 to 20 driving boats are sent to surround the school and drive it, by making noise underwater with 'trumpets' (Kasuya, 2002), into the bay of the village where the dolphins are stranded on the beach or surrounded with a long net and killed. Pelagic small cetaceans are also taken in the drive fishery including about 250 melon-headed whales (*Peponocephala electra*) that were captured in Suruga Bay (Nishiwaki and Norris, 1966); a pod of 14 pygmy killer whales (*Feresa attenuata*) was driven ashore from 30km off Futo, Japan (Nishiwaki *et al*., 1965).

Details of the sound production techniques used in this fishery have not been published in English except for a brief mention by Kasuya (2002). H. Kato (pers. comm. 2 May 2005) reported that each drive fishing vessel uses two 'trumpets' (Fig. 1) to produce sound. The trumpets are 445cm long with a shaft diameter of 4.5cm and a disk diameter of 22cm. The trumpets are hand-made by local blacksmiths in each village. The trumpets are lowered into the water on each side of the boat. The rod or handle is filled with water and hit with a hammer while the trumpet is underwater. A photograph of one of the Japanese driving boats with two trumpets in the water, one on each side of the boat, is shown in fig. 8 in Ohsumi (2001). Kishiro and Kasuya (1993) reviewed Japanese drive fisheries and reported that over 300,000 small cetaceans have been killed using this method since the end of World War II. This fishery is still active but smaller numbers of individuals are being taken. In addition to the traditional drives with the objective of obtaining dolphin meat for sale, Taiji fishermen have used these trumpets to help drive killer whales (*Orcinus orca*) and dolphins into Hatajiri Bay for sale for display in aquariums (Rossiter, 1997). Other small cetaceans have been collected from the drive fisheries for aquariums since the 1960s (Kasuya *et al*., 1984).

Fig. 1. The trumpet used to produce sound in the drive fisheries operating out of Taiji, Japan, consists of a metal pole, about 2.9-4.5m long, with a concave metal disk, about 22-26cm in diameter, attached to the bottom. One trumpet is used on each side of the boat. The fishermen place the disk end of the trumpet in the water and strike the pole with a hammer approximately every 2s, creating an acoustic barrier that helps the collection vessels herd schools of small cetaceans into the harbour. The insert shows a close-up of the concave disk that produces the sound.

Solomon Islands

Local people on Malaita, Solomon Islands have hunted schools of dolphins for 'an unknown but probably very long period' (Dawbin, 1966). The most important species in this fishery were the spinner dolphin (*Stenella longirostris*) and the pantropical spotted dolphin (Dawbin, 1966); the melon-headed whale was formerly important. Dawbin (1966) and Takekawa (1996a; 1996b; 2000) studied the traditional drive-hunting methods of the islanders.

According to Dawbin (1966), there were 10 hunting canoes which set off early in the morning and then fanned out and searched for schools of dolphins up to 7-10 miles offshore. When a school was sighted, the canoes approached and the fishermen began to make noises with rocks. Dawbin described the technique as follows:

> 'The centre paddler in each lays down his paddle, takes a large stone in each hand, then reaches over the side and clangs them violently together under water. The particular quality of the sound and percussion effects is intensely disturbing to most of the local species of porpoise. Some schools will not cross between two noise-making canoes spaced half a mile apart. The combined effect of the fleet of canoes gradually closing in is like an invisible net made of sounds waves only'.

Takekawa (2000) reported that the fishermen use rocks made of 'very hard, unsplit flint' that are about 15.5cm in diameter and described the hunting technique in detail. Once the dolphins are near shore, crew members jump in the water and hundreds of villagers rush in from the shore, all attempting to grab a dolphin and bring it onto the beach. Some of the dolphin meat is eaten and the beaks are removed for extraction of the teeth (Dawbin, 1966). The most valuable teeth are those of melon-headed whales, but hunters off Malaita may have reduced the local population of this species as the last one captured was in 1978 (Takekawa, 2000). Fraser's dolphin (*Lagenodelphis hosei*) also has valuable teeth and is or may have been a target of this fishery (Takekawa, 1996a; 1996b). Bottlenose dolphins (*Tursiops* sp.) were not a target of the traditional fishery as their teeth are not valued by the islanders. Furthermore, fishermen are not able to drive this species (Takekawa, 1996b). These bottlenose dolphins are members of a near-shore population that is presumably more accustomed to anthropogenic sound than more pelagic dolphins. Total numbers taken at the Solomons are not available but Dawbin (1966) reported that the scale of hunting increased enormously in 1964, resulting in catches of several thousand animals per year.

Although this fishery was thought to have ended in the mid 1960s (Dawbin, 1966), it still continues today (Takekawa, 2000). Fanalei is the only village that consistently catches dolphins. Hunts occur from December to April when the tradewinds do not blow. In 1994, fishermen hunted on 56 days, found dolphins on 24 days, caught dolphins on 12 days and captured a total of 865 dolphins (Takekawa, 2000).

Denmark

A drive fishery for harbour porpoises (*Phocoena phocoena*) is thought to have existed in inner Danish waters since the Stone Age, although the first written report is from 1357. Kinze (1995) estimated that the average annual take during the 1800s may have been about 1,000 animals at the six major catch sites in Danish waters, with a known minimum total of 59,028 animals taken for the years 1819-92. Möhl-Hansen (1954) reported that the water is beaten with sticks until the porpoises are driven into a small fjord where they enter fixed nets and are then pulled ashore, where they are removed and killed (see also Petersen, 1969).

Faroe Islands

A drive fishery for the long-finned pilot whale (*G. melas*) has existed in the Faroe Islands since Norse settlement occurred more than a thousand years ago (Zachariassen, 1993). Although pilot whales form the majority of the catch, bottlenose dolphins and Atlantic white-sided dolphins (*Lagenorhynchus acutus*) are also captured (Bloch *et al*., 1996). Northern bottlenose whales (*Hyperoodon ampullatus*) are also sometimes taken in this fishery but it is not clear if the methods used to drive them are the same as for pilot whales. The current fishery is conducted on an opportunistic basis throughout the year whenever pilot whales or dolphin schools are sighted in the vicinity of the islands. The fishermen drop stones or stones attached to lines behind the whales to form a wall of bubbles that the whales will not cross (Bloch, 2007). Entire schools are driven ashore by fishermen in small fishing boats by forming a semi-circle behind the whales and herding them slowly towards the shore. They are then killed by other men waiting on the shore. Some schools are driven in from as far as 20 to 30km offshore (Bloch *et al*., 1996). Excellent records exist on the number of whales captured in this fishery, which is still active today. A total of 117,546 pilot whales was captured from 1584 to 1883 (Mitchell, 1975a) and for all whales a total of 240,721 was captured from 1709-1992 (Zachariassen, 1993).

Newfoundland, Canada

Fishermen killed long-finned pilot whales in Newfoundland for several centuries (Templeman, 1966). The way in which the whales were hunted before motor boats were introduced does not seem to be documented. The modern phase of hunting pilot whales using the driving technique occurred in Trinity Bay and then expanded to neighbouring Bonavista Bay and sometimes Conception and Notre Dame Bays (Sergeant, 1962). Apparently, the sound of the engines on the fishing vessels was the only acoustic component to this fishery, as no references to any supplementary sound-producing device were found.

Small catcher vessels found schools of pilot whales in the open bay and slowly guided them towards the shore. When the whales were closer to shore, other fishermen in smaller motorboats and rowboats surrounded the schools in a crescent shape and continued to drive them until they reached shallow water where the whales were lanced (Sergeant, 1962).

Between 1948 and 1971, over 54,000 whales were harpooned or driven ashore (Mercer, 1975). After 1951, most of the whales were killed using the drive method. The Government of Canada closed this fishery on 22 December 1972, when commercial whaling was banned.

Less well-documented drive fisheries

There are many other reports of drive fisheries for small cetaceans in various parts of the world. These operations are poorly documented but the practice was apparently widespread. The extent to which acoustic techniques were used in some of these fisheries is unclear. Some of the more poorly documented cases by geographic region are listed below to show the widespread use of this fishing method, which probably developed independently in many areas of the world.

Hawaii

Peale (1848) reported 'sixty of these animals [melon-headed whales] were driven ashore by natives at Hilo Bay, island of Hawaii, at one time.' The technique used for the 'drive' was not described.

New England, USA

Holder (1903) described a pilot whale drive fishery at Provincetown, Cape Cod, Massachusetts, USA. The driving ashore of a fin whale was also recorded.

Ireland

Pilot whales were sometimes hunted using the driving technique. 'All kinds of boats, weapons and missiles were requisitioned for an attack on the herd' (O'Riordan, 1975).

Shetland
Turner (1871) reported a drive-hunt of 18 killer whales in Bressay Sound, Shetland in February 1871.

Kiribati
Grimble (1952) reported that natives from Kuma village in the Butaritari Atoll, Gilbert Islands hunted dolphins. It appears that the animals were hunted after they entered the inner waters of the lagoon, which measures approximately 30km east to west and 15km north to south, but neither the species hunted nor the exact method of hunting is described. In other parts of Kiribati (Kiritmati [Christmas] Island, Line Islands) Kim J. Andersen (pers. comm. 3 March 2008) described the hunting of melon headed whales in the early 1990s, 'I witnessed the locals herding a pod of melon-headed whales into the lagoon with boat and nets, then pushed them to the beach and butchered them'.

Taiwan
Fishermen in the Penghu Islands, Taiwan, captured bottlenose dolphins (*T. truncatus, T. aduncus*; Wang *et al*., 2000) in an acoustic drive fishery for over 50 years[1]. This was an opportunistic fishery near Sha-gang Village, in the northwest part of Hu-xi Township, that capitalised on sightings of dolphins by offshore fishing boats. When a dolphin school was sighted, part of the crew went back to port to notify other villagers, who set out in boats to catch them. While some boats attempted to block the direction in which the school was moving by men pounding on their boats to make noises to prevent the dolphins from continuing in that direction, other boats drove the dolphins up a deep gorge into shallow water towards the beach of Sha-gang Village, where they were stranded and killed. Capture efforts increased after 1975, when opportunities to export dolphin meat became available. In the early 1990s, the large numbers of dolphins being killed in this fishery became a conservation issue and it was closed. In the 1970s and 1980s some bottlenose dolphins were captured live for export to aquariums (Hammond and Leatherwood, 1984).

Drive fisheries for culling small cetaceans
The purpose of some drive fisheries is not to kill small cetaceans for human consumption but to reduce competition for fish. The best-known example is the hunt by fishermen on Iki Island in the Sea of Japan (Kasuya, 1985). When a local fishery began to decline, these fishermen drove large numbers of dolphins into bays and killed them. Between 1976 and 1982, the Iki fishermen killed approximately 6,000 small cetaceans. Most of these (4,147) were bottlenose dolphins but smaller numbers of false killer whales, Risso's dolphins, and Pacific white-sided dolphins, (*L. obliquidens*) were also taken. In 1982, small cetaceans stopped appearing near the island in large numbers. The fishermen probably still kill some dolphins but not in such large numbers as previously.

Deliberate incidental capture of small cetaceans
The best-known example of the deliberate incidental capture of small cetaceans (Mitchell, 1975b) is in the Eastern Tropical Pacific. Since the late 1950s, speed boats with powerful outboard engines have been used to herd various species of small cetaceans in the purse seine fishing operations for yellowfin tuna in this region (Gerrodette, 2002). The noise from the small boat engines is the only sound employed. For unknown reasons, large yellowfin tuna associate with dolphins. Fishermen exploit this association by herding both dolphins and tuna towards the vessel, encircling them in the net and then releasing the dolphins from the net. Two species, the northern offshore form of spotted dolphin and the eastern form of spinner dolphin account for most of the incidental kill in this fishery. This is by far the largest drive fishery impacting small cetaceans. Over six million dolphins were killed in this fishery between 1959 and 1989 (Bjørge *et al*., 1994).

This fishery is still active, with current catches in the low thousands (e.g. IWC, 2000). These takes are considered deliberate incidental catches. Due to improvements in fishing methods, more than 99% of the dolphins are now released alive (Gerrodette, 2002). However, many individual dolphins are repeatedly chased, captured, and released, which may have adverse effects on some individuals (NRC, 1992). For example, calves are unable to swim as fast as adults and many probably die after becoming separated from their mothers during chases (Noren and Edwards, 2007). This may help explain why the targeted dolphin populations are not recovering to the levels expected given the reduction in adult mortality (Noren and Edwards, 2007).

Use of sound for hunting large whales
Modern whaling started in the 1860s when it was mechanised with steam-powered catcher boats and explosive-head harpoons in Norway. Two hunting techniques were used: the *luse-jag*, stalking to surprise the whale; and the *prøysser jag*, persistent direct chasing or running down the whale. These early techniques are poorly documented but whalers soon discovered that sound could be useful when chasing and exhausting whales. One of the earliest examples was on the Korean coast in the early 20th century:

> 'if three or four ships are near each other when a school of Devilfish [gray whales, *Eschrichtius robustus*] are found, they draw together, each vessel going at full speed and making as much noise as possible. The whales at once sound, but as soon as they rise to spout the ships steam at them again. The Devilfish go down once more but do not stay under long, ascending at shorter intervals until finally they are ploughing along at the surface. The animals are 'scared up' as the gunners say, and become terrified to such a degree that everything is forgotten except the desire to get away'. (Andrews, 1914).

Andrews was studying the western gray whale at this time and reported that he was aided in his work by three Norwegian captains, H.G. Melson, Hans Hurum, and Johnson working for a Japanese whaling company (Toyo Hogei Kaisha) operating out of Ulsan, Korea with the steam catchers *SS Main* and *SS Rex Maru*. However, no additional details on acoustics are provided by Andrews (1914; 1916).

A more refined use of sound to assist with the capture of large whales was implemented after World War II. ASDIC (Anti-Submarine Detection Investigation Committee) was the term used by the English and French for the acoustic technology developed to hunt submarines during World War II. This name was replaced later by the American term SONAR (Sound Navigation and Ranging). Soon after the end of the war, whalers found that using ASDIC significantly improved the efficiency of the hunt. Improvements to the system occurred from the early stages as McCarthy (1948) made recommendations to improve the naval model to better serve the commercial requirements. The first commercial production model, called the 'whale finder' and made by Kelvin-Hughes, was available soon after the end of World War II (Tønnessen, 1970). By 1947,

[1] *http://www.ksdg.com.tw/peng/1001602/English/industry/industry-1.html.*

a British whaling company had equipped all their boats with ASDIC. By 1956, the 'Kelvin-Hughes Echowhale Finder' was installed on >40 catcher boats from Norway, Great Britain and Denmark (Tønnessen and Johnsen, 1982). In Japan, Ohsumi (1980b) reported that:

> 'ASDIC began to be installed into the pelagic catcher boats in 1958 and had been fitted to all of them by 1962. It was introduced in coastal whaling in 1950, but the rate of installation was slower than for pelagic whaling. All boats had ASDIC in 1970 and 1971 but one boat without ASDIC has been operating in coastal whaling even in recent years'.

When hunting sperm whales, ASDIC was not used to locate them initially, but to 'keep track of a whale which has dived, to facilitate positioning of the vessel when the whale re-surfaces' (IWC, 1980). Care had to be used when employing ASDIC for this purpose as it 'in fact can scare whales' (IWC, 1980). Tønnessen and Johnsen (1982) noted the 'ASDIC produces bursts of sound that enable diving whales to be echo-located. It can be used in whaling in two different ways: (1) in the case of baleen whales, it frightens the animals, which then swim very fast and near the surface, making them easier to see and tiring them more quickly; and (2) with sperm whales, its major use is in the tracking of lone animals while they are diving at great depths, enabling the catcher to be in the right place when they eventually surface.' Ohsumi (1980a) reported the same behavioural responses from Japanese whaling operations: 'When ASDIC is used, baleen whales swim faster and do not dive, but sperm whales dive for longer and do not swim on the surface, which hinders chasing'.

IWC (1980) noted that care had to be used when employing ASDIC to track diving sperm whales because it 'can scare whales'.

Many whalers reported that the sounds of the ASDIC appeared to irritate or frighten whales and Tønnesson (1970) noted that in the presence of ASDIC, whales were more likely to bolt directly away from the boats rather than dodge or cut from side to side. In the early 1950s, a gunner named Arne Skontorp developed the 'whale scarer' (hvalsskrekkapparat), which produced high frequency pulses and a German company manufactured a version of this as an 'ultrasound cannon' which was used during the 1952/53 season on the '*Olympic Lightning*' and 25 Norwegian boats (Tønnessen, 1970, p.521). The 'whale scarer' used six sources to generate ultrasonic pulses in three directions to 'scare' whales to the surface and 'induce panic and panting' to fatigue the whale as quickly as possible. The device was aimed directly at the whale, causing it to swim away in a straight line at full speed. The whale also began to surface more frequently than normal (Tønnessen, 1970). Skontorp originally attempted to combine the startler with ASDIC, but abandoned the attempt due to interference between the systems and ASDIC became the main acoustic device used by whalers.

While there is some debate about the contribution of ASDIC to whaling success in terms of numbers of whales killed and which species are best chased with it, there is little argument that it improved hunting efficiency. Mitchell *et al.* (1981) reviewed efficiency and effort in whaling operations with an emphasis on search tactics and the use of ASDIC and its contribution to the efficiency of whaling. They could find few technical details and little about the development of the ASDIC system in whaling operations. They found a gap, for instance, between the discovery of ASDIC, and its first use around 1946, and the dialogue regarding its contribution to the efficiency of whaling operations, which is found from about 1960 until the time of their review. Basically, the original system, as adapted for use in finding submarines, included a hull-mounted projector that could rotate 360^0 and send out an acoustic pulse; the bearing and delay of the returning echo would reveal the location of a whale to the operator. The experience of the operators varied significantly, with the more experienced being able to 'filter' out false echoes created by bubbles, thermal fronts, and their boat's own wake as they tried to find a whale. The system was only activated when a whale was within approximately 450-900m and it was of little or no use beyond about 1.6km. There is some evidence that hydrophones sometimes were included in these systems as Backus and Schevill (1966) reported that sperm whales responded to ASDIC by adjusting their click rates to match the ping intervals.

Ohsumi (1980a) noted for Japan that: 'In the 1950s and early 1960s the main object of pelagic whaling was the fin whale. Large catcher boats with ASDIC were efficient in taking this species as ASDIC caused it to swim faster and at the surface and the higher speed was needed to drive and chase it'. Horwood (1980) reviewed the efficiency of catcher vessels with and without ASDIC in the Japanese pelagic whaling operations. He showed that the average chasing time for sperm whales caught without the use of ASDIC was about 50% greater than for those caught using ASDIC.

Tens of thousands of large whales were killed with greater efficiency with ASDIC. Two examples of this are: (1) Japanese sperm whale operations using ASDIC killed over 50,000 animals in the North Pacific (Ohsumi, 1980b); and (2) over 17,000 sperm whales were landed in Durban, South Africa, after 1966 (when almost the entire fleet was fitted with ASDIC), although ASDIC was probably used for only about half of these captures (P. Best, pers. comm.); (Best, 1981).

Modern sonar techniques and technologies are, in some cases, being applied for mitigation of human activities. Stein *et al.* (2001) developed the high frequency marine mammal monitoring systems (HF/M3) with the goal of being able to detect whales before they enter areas where they would be exposed to harmful levels of sound. Stein *et al.* (2001) used mostly commercially available components operating in the 30-40kHz frequency range at levels up to 220dB re: 1μPa. The system utilises several modern techniques to maximise the detection ranges and probabilities while keeping the source levels as low as possible. The system has been tested in numerous field trials and its ability to detect marine mammals of various sizes has been qualitatively verified. Quantitative performance estimates have been generated using these field data and modelling. The estimates indicate that large adult whales (e.g. blue, *Balaenoptera musculus* and humpback, *Megaptera novaeangliae*) can be detected to ranges of 2,000m with near 100% probability. Detection probability for a medium-sized odontocete, however, falls below 90% at only 1,000m. The 220dB re: 1μPa source level necessary for maximum detection ranges is likely to induce temporary threshold hearing shifts at ranges <100m in odontocetes (Finneran *et al.*, 2005), though these specific frequencies have not been tested.

DISCUSSION

Fishermen around the world have used various types of low-intensity sounds for centuries to drive schools of small cetaceans ashore so that they could be killed and used for food or culled. During the 20th Century, the most commonly practiced method was the use of vessels to herd the small cetaceans to the shore. The acoustic components of these fisheries varied widely, ranging from hitting rocks together underwater to the engine noise from multiple small fishing boats. Since the end of World War II approximately 500,000 small cetaceans have been killed using the drive method in various parts of the world. Also, over seven million dolphins are estimated to have been killed by herding in the deliberate incidental catches in the eastern tropical Pacific, where dolphins associated with schools of tuna are herded by power boats, encircled by nets, and then released if possible The use of ASDIC (sonar) after World War II aided in the hunting and killing of tens of thousands of large whales during commercial whaling operations, starting in the 1950s and expanding rapidly.

Characteristics of the sounds used to hunt cetaceans

Most of the sounds used in drive fisheries have not been characterised. However, given the probable low intensities of sound used in most drive operations, it seems unlikely that the sounds would damage the auditory organs of the captured cetaceans although no one has looked for such damage. The sound of the 'trumpet' used by fishermen in Taiji, Japan, has been described and its effectiveness in hunting cetaceans confirmed experimentally by Akamatsu *et al*. (1993). These authors tested the reactions of two captive false killer whales to 15 different sound sources, specifically whether the whales swam directly away from the source. One of the sources tested was the same iron pipe and 'trumpet' used in all the Taiji whale fisheries, regardless of the target species. They indeed showed that the sound was effective in causing the whales to swim directly away from the source at received levels of 174dB re: 1μPa. Akamatsu *et al*. (1993) reported the source characteristics to be 205dB re: 1μPa at 0.2-5.2kHz, so in shallow water (i.e. under cylindrical spreading conditions, see Urick (1975)) whales at ranges of up to ~1200m may receive the levels that elicited the strong behavioural response. Therefore, it is not surprising that Japanese fishermen, using two of these 'trumpets' (Fig. 1) on each of several vessels at the same time, are able to herd schools of small cetaceans from tens of kilometres offshore into harbours or cause them to mass-strand on beaches.

It was not possible to find information on the exact characteristics of the sounds generated by either the 'whale scarer' or the ASDIC devices used in commercial whaling but they must have differed significantly from the probably low intensities used in most drive fisheries. For the ASDIC to have been effective to track whales at nearly 1,000m, the signals would have to have been rather intense. Modern systems used to detect animals at similar ranges that are specifically designed to keep source levels as low as possible (Stein *et al*., 2001) have levels as high as 220dB re: 1μPa and unlike modern systems, ASDIC systems were not designed to minimise source levels. At close range, the 'whale scarer' and the ASDIC signals may have had enough energy to cause damage (i.e. 230 dBpeak re: 1μPa for onset of a permanent threshold shift, see Southall *et al*. (2006) for a review), but neither the sounds used nor the animals captured are available for evaluation. The behavioural reaction, however, is clear from the records; baleen whales displayed a very strong reaction, a response that could certainly be interpreted as flight, even alarm. The pattern noted by Tønnessen and Johnsen (1982), that the ASDIC caused them to swim rapidly near the surface, is precisely the reaction observed by Nowacek *et al*. (2004) when they played a synthetic stimulus to North Atlantic right whales, *Eubalaena glacialis*. The rapid, sub-surface swimming displayed by the right whales could readily be interpreted as an anti-predator response that might have been elicited by the part of the stimulus that most closely resembled a biologically produced sound. The animals moved quickly away from the stimulus while remaining close to the surface to get air but minimised any surface cues a predator might use to find them. This response occurred even though the received level of the stimulus was relatively low, ~140dB re: 1μPa. This type of surfacing behaviour in response to anthropogenic sounds was also described by whalers hunting gray whales in Korean waters in the early 1900s and was more likely to occur when killer whales were in the area (Andrews, 1914). In contrast to the behaviour of baleen whales, sperm whales exposed to ASDIC tend to dive for longer periods of time (Ohsumi, 1980a). No evidence was found to suggest that any of the sounds used in drive fisheries or ASDIC devices lost any effectiveness during their use, though since the animals in the drive fisheries were killed, they certainly had no chance to habituate. If the ASDIC signals even remotely resembled biologically relevant sounds, e.g. those produced by a predator, the animals would not be expected to habituate. Habituation can, however, be complicated to predict based on the preferences and habits of the predator. Deecke *et al*. (2002) found that harbour seals did habituate to the social sounds of local, fish-eating killer whales but not to sounds from local mammal-eating whales. The seals reacted to sounds from unfamiliar fish-eating killer whales in the same way as they did to those of the local mammal-eating whales. If the right whales in the Nowacek *et al*. (2004) study interpreted the unfamiliar signals to which they were exposed as sounds produced by killer whales, they would not be expected to habituate them.

Management implications

The existence of drive fisheries worldwide and the strong reactions of baleen whales to anthropogenic sounds show that many species of cetaceans have strong avoidance responses to many types of anthropogenic sounds. The aversive response to a variety of relatively low level anthropogenic sounds shown by many small cetaceans suggests that mass-stranding may sometimes be a consequence of pelagic small cetaceans entering the unnatural habitat of shallow water while attempting to move away from anthropogenic sound sources. We believe that this possibility merits further investigation.

The sensitivity of small cetaceans to anthropogenic sound can also be used to help herd them away from areas where they are in danger of stranding or becoming entrapped. Observers are often alerted to potential mass strandings by an unusual behaviour known as 'milling', where a school of normally pelagic dolphins enters shallow water and begins to circle continually or move about haphazardly in a tightly packed group, with an occasional member breaking away and swimming towards the beach (Geraci and Lounsbury, 1993). Milling behaviour may last only a short time or up to several days before stranding occurs (or does not occur in some cases), so prompt intervention by humans maximises the chances of preventing stranding or rescuing animals that strand (Geraci and Lounsbury, 1993). Indeed, the 'milling' behaviour displayed by a group of melon-headed whales that would have mass-stranded in the shallow waters of Hanalei Bay, Kauai, Hawaii were it not for human intervention (Southall *et al*., 2006) closely resembled the behaviour described by Geraci and Lounsbury (1993) and Brownell *et al*. (Submitted).

It is important to find ways to prevent milling events from becoming fatal events. Geraci and Lounsbury (1993) recommended the use of 'noise, nets, people and boats to herd the animals offshore'. Use of acoustic deterrent devices (ADD), such as the pingers used to reduce bycatch of marine mammals in fishing nets (Barlow and Cameron, 2003) should be tested when milling events occur. An update on the use of ADDs is provided by a recent review (Nowacek *et al*., 2007). The combination of herding with small vessels and acoustic deterrents has been used with some success in preventing several milling events from becoming mass strandings for Atlantic white-sided dolphins in the Cape Cod region of Massachusetts (Touhey *et al*., 2003).

Bain (1995) described the sounds used to drive a pod of killer whales that had been entrapped for about six weeks in a very large tide pool (Barnes Lake, Alaska) out to sea. The method was similar to that used in Japanese drive fisheries. The whales were driven by 13 boats, 10 of which were equipped with hollow metal pipes. The pipes were struck with hammers at 3-10s intervals to produce a broadband pulse followed by a resonant tone with a fundamental frequency of about 300Hz. Depending on how hard the pipes were struck, levels of the broadband portion of the sound generally ranged from 165 to 175dB re: 1μPa at 1m. Sound levels received by the whales, which remained approximately 300m from the sound sources, were estimated at about 115-125dB. The effectiveness and potential disadvantageous side effects of ADDs and their partner, acoustic harassment devices (AHDs), for preventing stranding should be considered.

This review of the use of sound to help capture cetaceans provides additional evidence, not included in other reports (IWC, 2007; NRC, 2005), that the reduction of anthropogenic sound should be considered in management plans to protect cetacean habitats. It also indicates that a number of issues merit additional research including: (1) characterising the sounds used in the existing drive fisheries (i.e. Faroes, and the Solomon Islands); (2) characterising the sound produced by ASDIC devices; and (3) characterising the sounds produced by ADDs.

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REFERENCES

Akamatsu, T., Hatakeyama, Y. and Takatsu, N. 1993. Effects of pulse sounds on escape behavior of false killer whales. *Nippon Suisan Gakkaishi —Bulletin of the Japanese Society of Scientific Fisheries* 59(8): 1297-303.

Andrews, R.C. 1914. Monographs of the Pacific Cetacea. I. The California gray whale (*Rhachianectes glaucus* Cope). Its history, habits, external anatomy, osteology and relationships. *Mem. Am. Mus. Nat. Hist.* 1(5): 227-87.

Andrews, R.C. 1916. *Whale Hunting with Gun and Camera: a Naturalist's Account of the Modern Shore-whaling Industry, of Whales and their Habits, and of Hunting Experiences in Various Parts of the World*. D. Appleton and Co., New York. i-xxii + 333pp.

Au, W.W.L. 1993. *The Sonar of Dolphins*. Springer-Verlag, New York. 277pp.

Au, W.W.L. 2002. Echolocation. pp.358-67. *In*: Perrin, W.F., Wursig, B. and Thewissen, J.G.M. (eds). *Encyclopedia of Marine Mammals*. Academic Press, San Diego.

Backus, R.H. and Schevill, W.E. 1966. *Physeter* clicks. pp.510-28. *In*: Norris, K.S. (eds). *Whales, Dolphins and Porpoises*. Univ. Calif. Press, Berkeley. 789pp.

Bain, D.E. 1995. The use of sound to guide killer whales (*Orcinus orca*) entrapped in Barnes Lake, Alaska, to open water. Abstract presented to the 11th Biennial Conference on the Biology of Marine Mammals, Society for Marine Mammalogy, Orlando, Florida.

Barlow, J. and Cameron, G.A. 2003. Field experiments show that acoustic pingers reduce marine mammal bycatch in the California drift gill net fishery. *Mar. Mammal Sci.* 19(2): 265-83.

Best, P.B. 1981. Reconsideration of the catch per unit effort as an index of availability for sperm whales off Durban. *Rep. int. Whal. Commn* 31: 769-81.

Bjørge, A., Brownell, R.L., Jr., Donovan, G.P. and Perrin, W.F. 1994. Significant direct and incidental catches of small cetaceans. A report by the Scientific Committee of the International Whaling Commission to the United Nations Conference on Environment and Development (UNCED). *Rep. int. Whal. Commn (special issue)* 15: 75-130.

Bloch, D. 2007. *Pilot Whales and the Whale Drive. HNJ's Indispensable Guide to the Faroe Islands*. H.N. Jacobsens, Bokahandil. 64pp.

Bloch, D., Petersen, A. and Sigurjónsson, J. 1996. Strandings of striped dolphins *Stenella coeruleoalba* in Iceland and the Faroe Islands and sightings in the northeast Atlantic, north of 50 degrees N latitude. *Mar. Mammal Sci.* 12(1): 125-32.

Brownell, R.L., Jr. Ralls, K., Baumann, S. and Poole, M.M. Submitted. Behaviour of melon-headed whales near oceanic islands. *Mar. Mammal Sci.*

Caldwell, M.C. and Caldwell, D.K. 1965. Individualized whistle contours in bottlenose dolphins (*Tursiops truncatus*). *Nature, Lond.* 207(4995): 434-35.

Dawbin, W.H. 1966. Porpoises and porpoise hunting in Malaita. *Aust. Nat. Hist* 15(7): 207-11.

Deecke, V.B., Slater, P.J.B. and Ford, J.K.B. 2002. Selective habituation shapes acoustics predaotr recognition in harbour seals. *Nature* 420: 171-73.

Finneran, J.J., Carder, D.A., Schlundt, C.E. and Ridgeway, S.H. 2005. Temporary threshold shift in bottlenose dolphins (*Tursiops truncatus*) exposed to mid-frequency tones. *J. Acoust. Soc. Am.* 118(4): 2696-705.

Geraci, J.R. and Lounsbury, V.J. 1993. *Marine Mammals Ashore – A Field Guide For Strandings*. Texas A&M Sea Grant Publication, Galveston, Texas, USA. i-xi+305pp.

Gerrodette, T. 2002. Tuna-dolphin issue. pp.1269-73. *In*: Perrin, W.F., Würsig, B. and Thewissen, J.G.M. (eds). *Encyclopedia of Marine Mammals*. Academic Press, San Diego.

Grimble, A. 1952. *A Pattern of Islands*. John Murray, London. 260pp.

Hammond, D.D. and Leatherwood, S. 1984. Cetaceans live-captured for Ocean Park, Hong Kong, April 1974-February 1983. *Rep. int. Whal. Commn* 34: 491-95.

Holder, C.F. 1903. Trapping big game at sea. *Sci. Am.* 89: 391.

Horwood, J.W. 1980. Comparative efficiency of catcher boats with and without Asdic in Japanese pelagic whaling fleets. *Rep. int. Whal. Commn (special issue)* 2: 245-49.

International Whaling Commission. 2000. Report of the Scientific Committee. Annex I. Report of the Sub-Committee on Small Cetaceans. *J. Cetacean Res. Manage. (Suppl.)* 2: 235-57.

International Whaling Commission. 1980. Report of the Special Meeting on North Pacific Sperm Whale Assessments, Cronulla, November 1977. *Rep. int. Whal. Commn (special issue)* 2:1-10.

International Whaling Commission. 2007. Report of the Scientific Committee. Annex K. Report of the Standing Working Group on Environmental Concerns. *J. Cetacean Res. Manage. (Suppl.)* 9:227-96.

Kasuya, T. 1985. Fishery-dolphin conflict in the Iki Island area of Japan. pp.354. *In*: Beddington, J.R., Beverton, R.J.H. and Lavigne, D.M. (eds). *Marine Mammals and Fisheries*. George Allen and Unwin, London. 354pp.

Kasuya, T. 2002. Japanese whaling. pp.655-62. *In*: Perrin, W.F., Würsig, B. and Thewissen, J.G.M. (eds). *Encyclopedia of Marine Mammals*. Academic Press, San Diego.

Kasuya, T., Tobayama, T. and Matsui, S. 1984. Review of the live-capture of small cetaceans in Japan. *Rep. int. Whal. Commn* 34: 597-602.

Kinze, C. 1995. Exploitation of harbour porpoises (*Phocoena phocoena*) in Danish waters: A historical review. *Rep. int. Whal. Commn (special issue)* 16: 141-53.

Kishiro, T. and Kasuya, T. 1993. Review of Japanese dolphin drive fisheries and their status. *Rep. int. Whal. Commn* 43: 439-52.

McCarthy, W.J. 1948. The use of asdics in whaling. *Polar Rec.* 5: 220-32.

McDonald, M.A., Hildebrand, J. and Wiggins, S.M. 2006. Increases in deep ocean ambient noise in the northeast Pacific west of San Nicolas Island, California. *J. Acoust. Soc. Am.* 120: 711-18.

Mercer, M.C. 1975. Modified Leslie-DeLury population models of the long-finned pilot whale (*Globicephala melaena*) and annual production of the short-finned squid (*Illex illecebrosus*) based upon their interaction at Newfoundland. *J. Fish. Res. Bd Can.* 32(7): 1145-54.

Mitchell, E.D. 1975a. *Porpoise, Dolphin and Small Whale Fisheries of the World: Status and Problems*. No. 3 vols, *IUCN Monograph*. IUCN, Morges, Switzerland. 129pp.

Mitchell, E.D. 1975b. *Review of Biology and Fisheries for Smaller Cetaceans*. Journal of the Fisheries Research Board of Canada, 32(7), 875-1242.

Mitchell, E.D., Blaylock, G. and Kozicki, V.M. 1981. Modifiers of effort in whaling operations: with a survey of anecdotal sources on searching tactics and use of Asdic in the chase. *Center for Environmental Education Monograph Series*: 19pp.

Möhl-Hansen, U. 1954. Investigation of reproduction and growth of the porpoise (*Phocoena phocoena* (L)) from the Baltic. *Vidensk. Medd. Dan. Nathist. Foren.* 116: 369-96.

Nishiwaki, M., Kasuya, T., Kamiya, T., Tobayama, T. and Nakajima, M. 1965. *Feresa attentuata* captured at Pacific coast of Japan in 1963. *Sci. Rep. Whales Res. Inst., Tokyo* 19: 65-90.

Nishiwaki, M. and Norris, K.S. 1966. A new genus, *Peponocephala*, for the odontocete cetacean species *Electra electra*. *Sci. Rep. Whales Res. Inst., Tokyo* 20: 95-100.

Noren, S.R. and Edwards, E.F. 2007. Physiological and behavioural development in delphinid calves: implications for calf separation and mortality due to tuna purse-seine sets. *Mar. Mammal Sci.* 23: 15-29.

Nowacek, D., Thorne, L.H., Johnston, D.W. and Tyack, P.L. 2007. Reponses of cetaceans to anthropogenic noise. *Mammal Rev.* 37(2): 81-115.

Nowacek, D.P., Johnson, M.P. and Tyak, P.L. 2004. North Atlantic right whales *Eubalaena glacialis* ignore ships but respond to alerting stimuli. *Proc. Royal Soc., Biol. Sci.* 271(1536): 227-31.

NRC. 1992. *Dolphins and the Tuna Industry*. National Academy of Sciences, Washington. 176pp.

NRC. 2005. *National Research Council – Marine Mammal Populations and Ocean Noise – Determining when Noise Causes Biologically Significant Effects*. The National Academies Press, Washington DC. 142pp.

O'Riordan, C.E. 1975. Long-finned pilot whales, *Globicephala melaena*, driven ashore in Ireland, 1800-1973. *J. Fish. Res. Bd Can.* 32(7): 1101-03.

Ohsumi, S. 1972. Catch of marine mammals, mainly of small cetaceans, by local fisheries alomg the coast of Japan. *Bull. Far Seas Fish. Res. Lab.* 7: 137-66.

Ohsumi, S. 1980a. Catches of sperm whales by modern whaling in the North Pacific. *Rep. int. Whal. Commn (special issue)* 2: 11-18.

Ohsumi, S. 1980b. Criticism on Japanese fishing effort for sperm whales in the North Pacific. *Rep. int. Whal. Commn (special issue)* 2: 19-30.

Ohsumi, S. 2001. History on utilization of cetacean resources and the IWC. *Aquabiology* 134: 224-33. [In Japanese].

Peale, T.R. 1848. United States Exploring Expedition during the years 1838-42, under the command of Charles Wilkes. *Mammalia and Ornithology* 8A(25): xxv + 17-338.

Petersen, Å. 1969. *Marsvin og marsvinejaegere – Udgiverselskabet Middelfart by – og egnshistoriske musuem*. Middelfart, Denmark. 217pp. [In Danish].

Rossiter, W. 1997. The Taiji five revolution and action alert. *Cetacean Society International* 6(2): 1-2.

Sayigh, L.S., Tyack, P.L., Wells, R.S. and Scott, M.D. 1990. Signature whistles of free-ranging bottlenose dolphins *Tursiops truncatus*: stability and mother-offspring comparisons. *Behav. Ecol. Sociobiol.* 26: 247-60.

Sergeant, D.E. 1962. The biology of the pilot or pothead whale *Globicephala melaena* (Traill) in Newfoundland waters. *Bull. Fish. Res. Board Can.* 132: 1-84.

Southall, B.L., Braun, R., Gulland, F.M.D., Heard, A.D., Baird, R.W., Wilkin, S.M. and Rowles, T.K. 2006. Hawaiian melon-headed whale (*Peponocephala electra*) mass stranding event of July 3-4, 2004. *NOAA Technical Memorandum NMFS*: 73.

Stein, P.J., Rudzinsky, J., Binnam, M., Ellison, W.E. and Johnson, J. 2001. High frequency marine mammal mitigation active sonar system. pp.1388-91. *Proceedings of Oceans 2001*. MTS Conference and Exhibition.

Takekawa, D. 1996a. Ecological knowledge of Fanalei villagers about dolphins: dolphin hunting in the Solomon Islands. *Senri Ethnological Studies* 42: 55-65.

Takekawa, D. 1996b. The method of dolphin hunting and the distribution of teeth and meat: dolphin hunting in the Solomon Islands. *Senri Ethnological Studies* 42: 67-80.

Takekawa, D. 2000. Hunting method and the ecological knowledge of dolphins among the Fanalei villagers of Malaita, Solomon Islands. Secretariat of the Pacific Community. *Traditional Marine Resources and Knowledge Information Bulletin* 12: 3-11.

Templeman, W. 1966. Marine resources of Newfoundland. *Bull. Fish. Res. Board Can.* 154: 1-170.

Tønnessen, J.N. 1970. *Den Moderne Hvalfangsts Historie: den pelagiske fangst 1937-1969*. Utgitt av Norges Hvalfangstforbund 4, Oslo. 697pp. [In Norwegian].

Tønnessen, J.N. and Johnsen, A.O. 1982. *The History of Modern Whaling*. C. Hurst & Co., London. i-xx+798pp.

Touhey, K.M., Merigo, C., Moore, M.J. and Patchett, K. 2003. Mass stranding prevention: the effectiveness of herding and acoustic deterrents. Abstract presented to the 15th Biennial Conference on the Biology of Marine Mammals, Greensboro, NC, USA, 14-19 December 2003. [Available from: *http://www.marinemammalogy.org*].

Turner, W. 1871. On the gravid uterus and on the arrangement of the foetal membranes in the Cetacea. *Transactions of the Royal Society of Edinburgh* 26: 467-504.

Urick, R.J. 1975. *Principles of Underwater Sound*. Peninsula Publishing, Los Altos, California. 384pp.

Wang, J.Y., Chou, L.S. and White, B.N. 2000. Differences in the external morphology of two sympatric species of bottlenose dolphins (genus *Tursiops*) in the waters of China. *J. Mammal.* 81(4): 1157-65.

Watkins, W.A., Tyack, P. and Moore, K.E. 1987. The 20-Hz signals of finback whales (*Balaenoptera physalus*). *J. Acoust. Soc. Am.* 82(6): 1901-12.

Zachariassen, P. 1993. Pilot whale catches in Faroe Islands 1709-1991. *Rep. int. Whal. Commn (special issue)* 14: 69-88.

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