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ISTITUTO CENTRALE PER LA RICERCA
SCIENTIFICA E TECNOLOGICA APPLICATA AL MARE

Istituto Centrale per la Ricerca Applicata al Mare
Via di Casalotti 300, 00166 Roma

Report of the Workshop on Interactions between Dolphins and Fisheries in the Mediterranean: Evaluation of Mitigation Alternatives

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Edited by

Randall R. Reeves,
Andrew J. Read
and Giuseppe Notarbartolo di Sciara

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1. Introduction

There is a long history of interactions between marine mammals and coastal, small-scale commercial fisheries in the Mediterranean Sea. In the past, such interactions probably involved mainly common bottlenose dolphins (*Tursiops truncatus*), short-beaked common dolphins (*Delphinus delphis*) and Mediterranean monk seals (*Monachus monachus*). In recent times, issues related to perceived competition and direct conflict between dolphins and fisheries have become major concerns. Although the interactions themselves are not necessarily new, the situation is now complicated by several relatively recent developments. First, the conservation status of the marine mammal populations has changed. The Mediterranean monk seal is one of the world's most seriously endangered large mammal species. Both bottlenose and common dolphins are globally abundant, but their populations in the Mediterranean are thought to be geographically isolated from those in the Atlantic Ocean. Common dolphins have declined considerably throughout the Mediterranean basin and are currently being evaluated for the IUCN Red List of Threatened Animals. The status of bottlenose dolphins in this region is less certain, but some researchers believe that they have also declined. Second, small-scale fisheries in many parts of the Mediterranean have become economically marginal, whether due to the depletion of fish stocks, over-capitalisation, market changes or socio-cultural factors. These economic changes may be prompting fishermen to complain about the depredations by dolphins and to perceive these animals as competitors. Third, traditional approaches to predator control, e.g. culling or harassment, are no longer viewed as appropriate. Even if such measures were effective, they would not be legal, nor would they be ethically acceptable to many people. Finally, over the past two decades a variety of non-lethal acoustic devices to deter marine mammals have been developed and promoted for use in fisheries and aquaculture operations. The availability of these devices has raised expectations that novel approaches can be used to resolve current fishery-marine mammal conflicts in the Mediterranean.

With the above considerations in mind, the Italian government's Institute for Applied Marine Research (Istituto Centrale per la Ricerca Scientifica e Tecnologica Applicata al Mare, ICRAM) sponsored an international workshop to address the problem of conflict between dolphins and Mediterranean coastal fisheries. The workshop took place at ICRAM headquarters in Rome on 4-5 May 2001. Invited participants and observers came from eleven countries and several international organisations (Appendix 1). Their areas of expertise included dolphin behaviour and ecology, fish and marine mammal hearing physiology, fisheries ecology, monk seal biology and bio-acoustical engineering.

The workshop was organized by a steering committee consisting of Giuseppe Notarbartolo di Sciara, ICRAM; Andrew J. Read, Duke University; and Randall R. Reeves, IUCN/SSC Cetacean Specialist Group. Notarbartolo di Sciara acted as convener, Read chaired the workshop and Reeves served as workshop rapporteur. Caterina Fortuna of ICRAM was responsible for workshop organisation and logistics, and other ICRAM staff provided additional support.

2. Workshop Objectives

The objectives of the workshop included the following:

- Summarise the state of knowledge concerning conflicts between dolphins and fisheries in the Mediterranean;
- Evaluate the effectiveness of acoustic deterrents in reducing harmful interactions between dolphins and fisheries;
- Identify critical uncertainties about the effectiveness of these devices;
- Discuss potential impacts of these devices on cetaceans, monk seals, fish and other biota;
- Identify potential alternatives to acoustic devices for reducing conflicts between dolphins and fisheries; and
- Develop recommendations for scientific research, monitoring and management.

It was recognized that the problem of reducing by-catches of cetaceans in fisheries was inevitably linked to the problems being considered at the workshop, if for no other reason than because similar mitigation approaches were being developed or used to reduce the magnitude of by-catches. At the same time, however, it was deemed important to acknowledge that the role of acoustic (and other) devices in by-catch mitigation had been thoroughly reviewed in a series of previous workshops (Reeves *et al.*, 1996; Cox *et al.*, 1998; IWC, 2000, 2001) and that it was not the intention of the sponsors or conveners of the present workshop to re-consider that subject. Rather, they expected the workshop to focus explicitly on problems in the Mediterranean in which dolphin depredation was perceived by fishermen to be causing economic hardship.

The workshop agenda is attached as Appendix 2 and the list of background documents as Appendix 3.

3. Notes on Terminology

The workshop recognized that terminology for the various classes of acoustic deterrent devices was problematic. The term ‘acoustic harassment device’, or AHD, is commonly encountered in the literature and is generally understood as referring to certain devices used primarily to prevent pinniped depredation on cultured, and sometimes wild, fish stocks (Reeves *et al.*, 1996). The clear intent of AHDs is to cause pain or discomfort to the predator, preventing the animal from approaching a fish cage or fish aggregation. AHDs have relatively high source levels (>185dB re 1µP at 1m) and operate primarily in the mid to high frequency range (c. 5-30kHz) (Table 1). At the other extreme are the so-called ‘pingers’, which are low-intensity (generally <150dB re 1µP at 1m) transponders that operate in the mid to high frequencies between about 2.5-10kHz, with harmonics to much higher frequencies (Table 2). Pingers are designed explicitly to prevent small cetaceans from entangling in gill nets (Reeves *et al.*, 1996). Although the mode of action of pingers has been unclear, recent evidence indicates that their sounds are aversive to certain odontocetes (ICRAM/AHD/INFO 3; see later). In this report, all acoustic devices used to modify the behaviour of marine mammals are subsumed by the term ‘acoustic deterrent device’, while the term ‘AHD’ is used specifically for the high-intensity pinniped-exclusion devices and ‘pinger’ for the low-intensity bycatch-reduction devices. Some participants objected to the use of the term AHD, noting that the difference between these high-energy devices and the lower-energy pingers was merely a matter of degree. There was some support for this position but the workshop opted to maintain a terminology that was consistent with past (e.g. Reeves et al., 1996) and current usage.

During workshop discussions, it was pointed out that interactions may be occurring already, or soon could begin to occur, between dolphins and aquaculture facilities in the Mediterranean. Therefore, throughout this report it should be understood that general references to dolphin interactions with ‘fisheries’ are also intended to apply to interactions between dolphins and aquaculture (or mariculture) operations.

There may be some confusion about the distinction made in this report between ‘predation’ and ‘depredation’. As used herein, predation refers to predators preying on free-ranging prey, whereas depredation refers to predators taking, or attempting to take, prey that are confined in pens or that have been caught in fishing gear.

4. Workshop Findings

4.1. Current conflicts between dolphins and fisheries in the Mediterranean Sea

The focus of the workshop was on situations in which dolphins deliberately utilize fishing gear (or aquaculture facilities) as part of a foraging strategy. Most available information about such behaviour is anecdotal and unpublished. Notarbartolo di Sciara provided an initial overview, and participants with first-hand experience in the Mediterranean then offered more detailed accounts for specific areas.

4.1.1. Identification of interacting dolphins and fisheries

Most interactions are believed to involve bottlenose dolphins, which are the most abundant coastal small cetaceans in the Mediterranean. Their diet is diverse and likely includes many of the demersal fishes that are the targets of small-scale fisheries. The distribution of short-beaked common dolphins in the Mediterranean is both coastal and pelagic, depending on the area. They are, for example, found in near-shore habitats in western Greece where they sometimes occupy shallower water than *Tursiops*. For two reasons, common dolphins are less likely than bottlenose dolphins to be involved extensively in conflicts with fisheries. First, their diet is dominated by small, epipelagic schooling fishes which are not targeted by gill and trammel net fisheries in which most conflicts have been reported (but see Tringali *et al.*, 2001). Second, their abundance in the Mediterranean has declined dramatically in recent decades such that their continued survival in the region has been cast into doubt. There is nevertheless some evidence suggesting that common dolphins may be involved in fishery depredations in Tunisia (Torchia, pers. comm.). The striped dolphin, by far the most abundant cetacean in the Mediterranean, is sufficiently pelagic in distribution that it is unlikely to interact with coastal fisheries. Risso's dolphin (*Grampus griseus*), another largely pelagic species, is involved in fishery interactions in at least one area (see below). Monk seals are at present too scarce to affect fisheries outside selected coastal areas of Greece and Turkey.

Unlike some other parts of the world, the Mediterranean appears to have only a coastal form of bottlenose dolphin, which occurs as a series of largely resident communities. The distribution is best described as patchy and discontinuous. No migratory movements by bottlenose dolphins have been reported in the Mediterranean.

Conflicts with dolphins have been reported primarily in bottom-set trammel and gill nets. Dolphins also interact to some extent with trawl nets (e.g. Bearzi and Notarbartolo di Sciara, 1997; Pace et al., 1999; Mazzanti, 2001), and occasionally with small purse seines or ring nets targeting pelagic schooling fishes (Goodson, pers. comm.). It was suggested that the presence of dolphins may reduce purse seine catches, because dolphins cause the fish schools to disperse or otherwise make them less easy to catch (Vidoris, pers. comm.). In a night fishery for mesopelagic squid southwest of Naples, Risso's dolphins approach the illuminated area to forage, in the process angering fishermen (Notarbartolo di Sciara, pers. comm.).

Small-scale commercial fisheries in coastal waters of the Mediterranean, like those elsewhere in the world, are likely to be economically marginal, and therefore even relatively small losses to dolphin depredation can have a large impact on a fisherman's livelihood. Workshop participants emphasized that conflicts between dolphins and fisheries in the Mediterranean were not new. In Greece, for example, they date back at least 40 years (Vidoris, pers. comm.), and in both Italy and the former Yugoslavia bounties were paid for killing of dolphins, considered vermin, until the 1950s (Notarbartolo di Sciara, pers. comm.). Awareness and public discourse about the problem, however, seems to have increased in recent years. Among the many possible reasons for this increased awareness are that (a) fishermen have learned of opportunities to gain compensation and have therefore become more vocal and assertive, and (b) some coastal fisheries have moved farther offshore as near-shore fish availability has declined and/or vessel capacity has grown (Pelusi, pers. comm.).

4.1.2. Nature and geographic scope of interactions

The negative effects of dolphins on coastal fisheries in the Mediterranean are said to consist of three main elements, as follows: (1) damage to gear in the form of holes torn in the netting as the dolphins attempt to remove fish; (2) reduction in the amount or value of the catch as the dolphins mutilate or remove caught fish from the net; and (3) reduction in the size of the catch as the dolphins' presence causes fish to flee from the vicinity of the nets. In some instances fishermen also complain of more general ecological competition with dolphins, i.e. that predation by dolphins reduces the amount of fish available to fisheries. Torn netting is particularly costly because it involves the loss of both money and time by the fishermen.

Within the Mediterranean, studies of fishery-dolphin interactions have been initiated in at least three areas. In Italy's Asinara Island National Park, northwestern Sardinia, an attempt has been made to quantify the impact of dolphin depredation in the trammel net fishery for red mullet (*Mullus surmuletus*) (ICRAM/AHD/INFO 17, 21; also see Cannas *et al.*, 1994; Lauriano *et al.*, 2001; see below). In two areas of Sicily (Catania and Favignana) a European Commission-sponsored study (project ADEPTs) has been initiated to test the feasibility and efficacy of using pingers to reduce dolphin depredation in trammel and gill net fisheries (ICRAM/AHD/INFO 20, 20a; see below). In the Balearic Islands, studies by the University of Barcelona from 1992-95 indicated that about 30 bottlenose dolphins were dying annually as a result of entanglement or direct killing by fishermen in retaliation for depredation on trammel nets and shore-anchored gill nets set for red mullet and cuttlefish (*Sepia officinalis*) (ICRAM/AHD/INFO 25) (also see Silvani *et al.*, 1992; Gazo *et al.*, 2001; see below). A program sponsored by the Spanish and Balearic governments was initiated in October 2000, involving the use of pingers to deter dolphins and protect these fisheries. In addition to those three areas, there is some information on conflicts between dolphins and fisheries in the Thracian Sea (northern Aegean, Greece) (Mitra *et al.*, 2001), Tyrrhenian Sea (Mussi *et al.*, 1999) and Ionian Sea (Tringali *et al.*, 2001), the latter involving a fishery for European anchovies (*Engraulis encrasicolus*). Notarbartolo also mentioned a problem with dolphin interactions in a flounder fishery north of Venice.

There are numerous anecdotal reports of fishermen taking retaliatory measures against dolphins. It is not unusual for bullet wounds to be found on stranded animals, and stories are circulating about fishermen attempting to feed dolphins with fish containing needles or poison (Notarbartolo di Sciara, pers. comm.). Fishermen in Catania, Sicily, reportedly have used blackpowder fireworks or homemade bombs to scare dolphins away from their nets (ICRAM/AHD/INFO 20a; Quero *et al.*, 2000; Tringali *et al.*, 2001).

Some discussion was devoted to the question of whether reduced prey availability might be a causal factor in interactions between dolphins and Mediterranean fisheries. No clear evidence was available to address the question. It was noted, however, that conflict occurs in certain areas where target fish stocks are relatively abundant (e.g. Asinara Island) whilst in some other areas where target fish stocks are depleted there is little or no conflict between dolphins and fisheries (e.g. Croatia) (Fortuna, pers. comm.). Ecological models may be useful tools with which to better understand the interactions between dolphins, fisheries and other ecosystem components. For example, modelling might elucidate counter-intuitive consequences of predator-prey relationships, which, in turn, could help explain why dolphin depredations occur in some areas and not in others. The assumptions used in such models, e.g. related to energy budgets, need to be viewed critically, and, as competition cannot be measured directly, changes in habitat use might need to be used as proxies for effects of competition.. The workshop noted that fish stock assessment, and fishery management generally, are inadequate in the Mediterranean and that dolphins may often serve as scapegoats for unsustainable fishing practices.

Although no detailed information was available to the workshop concerning aquaculture operations in the Mediterranean, Notarbartolo di Sciara and Pelusi reported that this sector is expanding rapidly in Italy and Greece. Pelusi emphasized that in Italy the pens are generally in waters 10-50m deep rather than in shallow near-shore waters. It was unclear whether dolphins (presumably *Tursiops*) are attracted to the aquaculture pens in attempts to gain access to the fish inside, or instead simply take advantage of 'food chains' created near the pens by spilled feed etc. (Bearzi *et al.*, 2001; Diaz Lopez *et al.*, 2001). There were reports of net damage and fish removal but in Greece at least, some or many of these problems may have been caused by monk seals rather than dolphins (Vidoris, pers. comm.).

Notarbartolo reported that ICRAM had initiated a mapping project to provide an inventory of fisheries and dolphin distribution along the Italian coast, with a view to identifying known or potential 'hotspots' of interaction. He noted that there were sites where dolphins reportedly had a large impact on fisheries (e.g. in Sicily and Sardinia) but also areas where dolphins and fisheries apparently co-existed without conflict.

The workshop **strongly recommended** that this mapping project be completed as soon as possible, and that it be expanded to encompass other parts of the Mediterranean where interactions have been reported or suspected to occur (e.g. Spain, Tunisia, Cyprus, Greece and possibly Croatia).

4.1.3. Quantification of economic effects on fisheries

Most information on the economic effects of dolphin interactions with Mediterranean fisheries is qualitative and anecdotal. A pilot study initiated in January 1999 attempted to quantify these effects for trammel net fisheries in Asinara National Park, Sardinia (ICRAM/AHD/INFO 17, 21; summarized to the workshop by Lauriano). Interactions between dolphins and three classes of fisheries were investigated for the period January 1999 - October 2000. No interactions were documented in the large-mesh (64-72mm) fishery for lobsters (*Palinurus elephas*) and interactions were judged insignificant in the medium-mesh (32-50mm) fisheries for squids, rockfishes, Scorpaenidae and cuttlefish. The greatest interactions and most significant economic effects occurred in the small-mesh (27mm) fishery for red mullet that took place mainly from September-December. The nets, each no more than 700m long, were set early in the morning for periods of 2-4hr. Several small fishing vessels (< 10 gross tons) worked in the same area simultaneously, using an average of about 2.2km of net/boat. Most of the fishing was conducted in depths of 20-25m. Observers were deployed on inflatable boats to document dolphin activity around the nets. Catch rates (in kg/km of net) of sets with and without dolphins present were compared to estimate the mean reduction in yield attributable to dolphin interactions. It was estimated that catch rates of red mullet declined by 4kg/km of netting per night when dolphins were seen around the nets. Although it was recognized that fishermen also lost time and money when their nets were damaged (most fishermen repair their own nets) or when fish were partially eaten or damaged in the nets, no attempt was made to quantify these costs. Lauriano explained that although there was no unequivocal evidence that any of the observed types of fish and net damage were caused by dolphin depredation, there was a strong association between dolphin presence and certain types of fish and net damage.

No data exist on fish abundance or biomass in the national park waters, which were first opened to commercial fishing about two years ago. The park has no zoning or other form of management although entry to the fishery is limited by a licensing scheme (about 80 boats presently have licences to fish in the park). In discussion it was noted that despite the observed correlation between catch-per-unit-effort and the presence or absence of dolphins around red mullet nets, it is always possible that local fluctuations in fish abundance would influence both the catch rate and the presence of dolphins.

Studies were underway in Sicily (project ADEPTs) to evaluate the effectiveness of pingers in reducing the economic impacts of dolphins on trammel net, gill net, longline and purse seine fisheries (Chiofalo *et al.*, 2000; ICRAM/AHD/INFO 20, 20a). Goodson indicated that changes in catch-per-unit-effort were being used as the primary index for effects but also that net damage was extensive, leading to real costs to fishermen in terms of time and materials (Quero *et al.*, 2000; ICRAM/AHD/INFO 20a).

Three indices of effects were being used in studies of trammel net fisheries in Mallorca, as follows (ICRAM/AHD/INFO 25): (1) total weight of catches of target species, (2) number of new holes larger than 20cm diameter in the nets after each haul and (3) direct observations of dolphins feeding in the vicinity of the nets. The Mallorcan fishermen set their nets (approximately 3km long) for red mullet in the evening and hauled them after about 3hr. The somewhat shorter cuttlefish nets were left in the water overnight (Gazo, pers. comm.).

Neither of the studies in Sicily and Mallorca is attempting explicitly to quantify the economic effects of dolphins on the fisheries.

During discussion, it was clear that a rigorous methodology needed to be developed for quantifying the economic effects of dolphins on Mediterranean fisheries. Northridge and Lauriano outlined several approaches for the workshop (Appendix 4).

4.1.4. Quantification of effects on dolphin populations

Workshop participants also expressed concern about the adverse effects on dolphin populations of such operational interactions between dolphins and fisheries. While it was recognized that ecological interactions with fisheries, such as competition for the same fish or invertebrate resources, could affect dolphin populations, these potential effects were generally considered outside the scope of the workshop.

Operational interactions with fisheries could have various kinds of effects on dolphins, including: (1) enhanced foraging success, (2) changed distribution and habitat use as the dolphins are attracted to areas with fishing operations, (3) mortality from entanglement in fishing gear and (4) injury or mortality from retaliatory measures taken by fishermen. Programs that monitor strandings and bycatch, including specimen collection and necropsy, can play a role in at least identifying such effects, if not also in helping to quantify them. Such programs should include training of local scientists to perform dissections and preserve tissues. Networks should be established to facilitate communication between individuals who respond to strandings or entanglements, and experts who can either attend or advise on release or necropsy procedures. There also needs to be an efficient mechanism for ensuring that tissues are appropriately analysed, particularly with regard to assessments of acoustic or blunt trauma. A training workshop may an efficient way of implementing these ideas.

No relevant quantitative data were available to the workshop on the adverse effects of such operational interactions on dolphin populations. Participants **strongly recommended** that better baseline information be obtained on coastal dolphin populations in the Mediterranean, including population structure, movements, abundance and behaviour patterns. All participants agreed that photo-identification would be an essential tool for obtaining this required information.

4.2. Overview of acoustic deterrent devices

4.2.1. Characterization of acoustic features

Various lines of evidence suggesting that the mode of action for pingers, at least for species such as the harbour porpoise, is aversion rather than simply 'alerting' an animal so that it is more likely to echolocate and detect the net (ICRAM/AHD/INFO 3). Free-ranging porpoises generally respond to pingers at distances beyond the range at which their biosonar could detect a net. Also, the responses of captive cetaceans and pinnipeds are consistent with the hypothesis that pinger signals are aversive. Finally, free-ranging harbour porpoises (*Phocoena phocoena*) have been found to *reduce* their echolocation activity near nets with active pingers (ICRAM/AHD/INFO 4; Cox *et al.*, 2001) and to actively avoid the ensonified area near active pingers (Gearin *et al.*, 2000; Cox *et al.*, 2001; Culik *et al.*, 2001).

Barlow and his colleagues investigated the response to pingers of bottlenose dolphins and other delphinids in captivity (ICRAM/AHD/INFO 3). Moreover, field experiments in the California drift net fishery have found significantly lower bycatch rates of all cetaceans combined , and of common dolphins alone, in pingered nets (Barlow and Cameron, 1999). Some workshop participants nevertheless expressed skepticism about the responsiveness of *Tursiops* to pinger-type signals. Work by V. Cockcroft and his students in South Africa found *Tursiops* unresponsive to pingers. A field study by one of Würsig's graduate students (Holly Fortenberry) found that bottlenose dolphins moving parallel to shore adjusted their headings but did not change swimming speeds as they encountered a buoyed pinger. Dawson (ICRAM/AHD/INFO 2) evaluated a study of the response to pingers by Hector's dolphin (*Cephalorhynchus hectori*), another delphinid, and concluded that no significant response was documented in these trials.

The workshop agreed that pingers and AHDs can appropriately be viewed as occurring along a continuum, perhaps involving simple annoyance at one end and physical pain or even permanent hearing damage at the other. At the same time, however, participants wished to stress that there is a large and meaningful difference between pingers and AHDs not only in terms of their power output, but also in the ways they are deployed (see Tables 1 and 2). Deployment of AHDs at aquaculture facilities is essentially permanent or constant, while deployment of pingers in fishing gear is usually sporadic and unpredictable (Johnston and Woodley, 1998).

4.2.2. Review of uses of acoustic deterrent devices with marine mammals

AHDs were developed primarily to deter pinnipeds from approaching aquaculture facilities rather than for use with active fishing operations (e.g. Reeves *et al.*, 1996; Johnston and

Woodley, 1998; ICRAM/AHD/INFO5, 8). Several examples of their use in non-aquaculture contexts were mentioned - e.g. to deter killer whales from longlines in Norway (Goodson, pers. comm.) and phocid seals from salmon pound nets in Sweden (Northridge, pers. comm.). In Washington and British Columbia they have been used to protect salmonids from seal and sea lion predation (Yurk and Trites, 2000). Barlow described the proposed deployment by some California fishermen of a concussive shock wave (source level: 220-240 dB re 1µP at 1m) intended to protect their catch from pinnipeds.

Although pingers have been used mainly in the context of cetacean by-catch reduction, a few examples of their use in other contexts were noted. V. Cockcroft reportedly conducted field trials attempting to protect longlines from depredation by false killer whales (*Pseudorca crassidens*) in the Indian Ocean. M. Cawthorn tried to use pingers to keep otariids away from trawlers off the west coast of New Zealand (Dawson, pers. comm.). Johnston reported two examples in which pingers were deployed to help prevent groups of odontocetes from stranding. No details concerning the methods and results of these trials were available to the workshop.

4.2.3. Documented or potential effects of acoustic deterrents on cetaceans

There is a growing body of theoretical, observational and experimental data on the effects of AHDs on cetacean movements and distribution. These data, summarized for the workshop by Johnston (ICRAM/AHD/INFO 9) and Würsig (ICRAM/AHD/INFO 5), consistently indicated that harbour porpoises were deterred from approaching closer than about a kilometre to an active AHD and that their behaviour and movements were influenced at distances well beyond a kilometre. This means that harbour porpoises are likely to be excluded from habitat within at least a portion of the ensonified radius of an active AHD. Moreover, an unpublished study by A.B. Morton and H.K. Symonds in British Columbia found a strong inverse correlation between the presence of AHDs and the use of inshore waters by killer whales, again suggesting that the animals were displaced from large areas. The devices involved in these studies were designed for continuous operation, and it is possible that devices designed to operate non-continuously would have less dramatic effects on cetaceans.

There is less information on the potentially adverse effects of pingers on cetaceans. In general, participants indicated that they would not expect the use of low-power acoustic devices to be effective in keeping animals, and perhaps especially bottlenose dolphins, away from a food source (see later). There was concern that sounds sufficiently intense to deter *Tursiops* would likely be powerful enough to exclude at least some other species from a wider area.

Ketten summarized the types of hearing loss or ear damage in cetaceans that could possibly be caused by exposure to acoustic deterrent devices (Ketten, 1998; also see Ketten et al., 1993). The primary concern is over-stimulation, i.e. exceeding the elastic limits of the ear. Over-stimulation is a composite phenomenon involving duration, level, spectral content and a temporal pattern of the received level vs. the tolerance of the ear for each species. In general, received levels below about 75-80dB re: 1µP at 1m would not be expected to cause a temporary threshold shift (TTS). Sound intensities higher than about 130dB re: 1µP at 1m are more likely to cause TTS but this would obviously depend on frequency sensitivity and duration of exposure. High levels of exposure do not necessarily impair hearing only at or near the peak frequency but rather can often impair hearing at frequencies higher than the peak spectra of the source. For example, in laboratory experiments on TTS, exposures to mid-range pure tones also produced substantial TTS at one-half to one octave above the source frequency and the spread of loss is greater to higher than to lower frequencies.

Frequency sensitivity is highly species-dependent. Intermittent exposure is always preferable to continuous exposure. Impulsive noise is generally considered more likely to damage hearing from shorter exposures and in more species than narrowband noise because impulsive sounds are generally intense, they excite broad areas of the inner ear simultaneously, and they have a sudden onset. Consequently, there is no time for the ear to ameliorate the incoming signal, e.g. through the middle ear reflex, and the inner ear is fully exposed to a peak pressure that is likely to exceed its dynamic range at several frequencies.

Among factors to consider in assessing risk of hearing damage are habituation, prior exposure and inherent species and individual differences in sensitivity. In longitudinal studies, it has been shown that dolphin hearing decays with age. For example, in some male *Tursiops* all sensitivity to frequencies higher than 55kHz has been lost by age 16-20yr (Ridgway and Carder, 1997). There are good data on hearing changes in captive animals and a high percentage of stranded cetaceans and pinnipeds show evidence of hearing loss. However, such loss could be due to chronic infection or other disease syndromes in these individuals. What is of most relevance in the present context is a population-level effect, which is difficult to demonstrate empirically.

There was discussion about the implications of the high-energy (to 220dB re: 1µP at 1m) impulsive sounds produced by bottlenose dolphins themselves. It is possible that these animals affect one another's hearing. Tyack noted, however, that the impacts of intense clicks may be moderated by the fact that the energy is highly directional when the animals are echolocating, yet Amundin asserted that in captivity the animals appear to direct the full force of their sound-generation abilities at one another during social interactions.

When asked to characterize the type of signal that would likely give maximal deterrence with minimal risk, Ketten responded that it should be impulsive rather than tonal, in the ultrasonic range between roughly 20-100kHz, with long intervals, loud enough to be highly aversive and sufficiently varied to preclude habituation. The aversive nature of the stimulus will presumably enhance effectiveness, reduce the required duration of exposure and thus minimize hearing loss. The signal would obviously need to be designed so that it would not adversely affect target species of the fishery. In order to optimize signal parameters and prevent undesirable effects on a variety of biota, considerable scrutiny and investigation would need to be devoted to comparing device parameters with the acoustic sensitivities of all relevant species.

Some participants expressed unease at the notion of exposing dolphins in the Mediterranean to any additional acoustic stimulation, in part because these animals are legally protected and in part because noise from acoustic deterrents would be superimposed on an already substantial burden of artificial sound in the marine environment. Würsig pointed out the possibility of positive feedback: as dolphin hearing is progressively impaired from the cumulative exposure to anthropogenic noise, they may become increasingly dependent on interacting with fisheries and aquaculture operations to obtain food.

Ketten advised that it would be difficult or impossible to identify an acoustic stimulus that is at once sufficiently intensive to function as an effective deterrent to bottlenose dolphins, whilst ruling out any possibility of harmful impacts on dolphins or other biota. She expressed skepticism towards the possibility of achieving acoustic ‘annoyance’ in dolphins without some risk of physical harm. In searching for alternative technologies, she warned that mid-sonic range sounds can be more harmful than ultrasonic sounds because of the risk of resonance effects.

Concern was also expressed by workshop participants that extensive deployment of acoustic deterrent devices to control depredation by bottlenose dolphins in the Mediterranean could incidentally affect common dolphins and sperm whales. Tyack referred to the documented responses of sperm whales to calibration pingers in the 6-13kHz range (Watkins and Schevill, 1975), noting that low-frequency components of emissions from deterrent devices could be heard at considerable distances by sperm whales and, in turn, affect their behaviour.

4.2.4. Potential effects on other biota

In considering the potentially adverse effects on other components of the Mediterranean ecosystem, monk seals are of particular concern. Turkey and the Greek islands are the two main areas where monk seals are still found. Acoustic deterrents could affect monk seals in at least two ways. The noise could keep them away from preferred haul-out areas, or attract them to nets (the ‘dinner bell’ effect) and thus contribute to entanglement or exacerbate conflict with fishermen. Most monk seal mortality in the Mediterranean is thought to be the result of retaliation by fishermen against seals because of perceived competition or damage to catch and gear. Ketten pointed out that there is no audiogram for the Mediterranean monk seal and that the existing audiogram for the related Hawaiian monk seal (*Monachus schauinslandi*) is based on a single animal whose hearing curve has some characteristics that suggest its responses may have been affected by disease or age.

The workshop **underlined** the importance of obtaining better information on monk seal hearing so that the potential effects of acoustic pollution on this highly endangered marine mammal could be properly assessed. Also, noting that the breeding and haul-out areas of Mediterranean monk seals are extremely circumscribed, the workshop **strongly recommended** that any use of acoustic devices in or near such areas be considered carefully. In the absence of good information to the contrary, a precautionary assumption would be that acoustic deterrents could adversely affect the recovery of this species.

Popper provided a concise summary of what is known about hearing in fishes, sharks, turtles and some invertebrates (Appendix 5). The potential for impacts on target and non-target species (vertebrate and invertebrate) is uncertain but needs to be considered in the design and use of acoustic deterrent devices. Concern was expressed that animals experiencing long-term exposure to acoustic deterrents, including animals in aquaculture and mariculture environments, may experience adverse physiological effects, including hearing loss or increase in stress that would result in decreased growth and reproduction. This possibility raises animal-welfare issues (e.g. ICRAM/AHD/INFO 8), apart from the obvious concern about product quality and quantity. In addition, there is concern that catches may be reduced if the signals from acoustic deterrent devices are within the hearing ranges of fishes that are able to detect ultrasonic sounds.

The potential effects on seabird hearing have generally been ignored although pingers have been demonstrated to be effective in reducing the by-catch of some seabird species in gill nets (Melvin *et al.*, 1999). There is some evidence of bi-modal hearing (in air and under water) in seabirds (Ketten et al., 1999).

4.3. Current use of acoustic deterrent devices in the Mediterranean

No specific evidence was presented to the workshop concerning the current use of AHDs in the Mediterranean although there are reports of fishermen at Mallorca using 'seal scrammers' to keep dolphins away from their nets in the past. Also, Notarbartolo di Sciara described a steel-pipe clanger used in Tunisia to drive dolphins away from nets until they quickly habituated. Also, some use may have been made of AHDs in Cyprus but no details were available (Notarbartolo di Sciara, pers. comm.). Elsewhere in the world, there has been a trend of increasing power output in acoustic devices to protect aquaculture facilities from pinniped depredation; a similar trend might be expected with devices used to deter dolphins from fishing gear in the Mediterranean. Würsig added that monk seal interactions with fishing gear and aquaculture operations in Greece and Turkey could lead to AHD use there. Low-power acoustic devices have been obtained and deployed by some Greek fishermen (Goodson, pers. comm.). In the Balearic Islands fishermen are prohibited from using pingers unless a government observer is on board (Gazo, pers. comm.).

Several ongoing field trials using pingers were described and discussed.

At Mallorca, Gazo's study involves placing AQUAmark 100 pingers (see Table 2) on a 500m segment of a 3500m net, with blind controls, to determine whether these pingers are effective deterrents against dolphin depredation. Fish catch rates, damage to the nets and sightings of dolphins in the area of the net are used as indices of effectiveness. To date, results of these trials are inconclusive. Gazo noted that new holes were found in nets even when no dolphins were reported in the vicinity. This raised the possibility that at least some of the damage attributed to dolphins has been caused by other predators, snags or an unidentified factor.

In Sicily, the ADEPTs study involves field trials using about 12 pingers placed at one end of a trammel or gill net, with variable duty cycles, frequencies and levels. Results should be available; from the EC by the end of 2001 (Goodson, pers. comm.).

A third initiative was described to the workshop by S. Mazzola of the Istituto di Ricerche sulle Risorse Marine e Ambiente CNR (ICRAM/AHD/INFO 6). A device developed at the Severtsov Institute of Evolutionary Morphology and Animal Ecology in Russia was tested in captivity and then in sea trials in Sicily. This device apparently emitted killer whale and bottlenose dolphin signals in an attempt to deter dolphins from approaching fishing gear. Results were disappointing as the dolphins exhibited waning responsiveness to the signals with time, leading Mazzola and his colleagues to begin investigating 'physiological' (as opposed to ‘psychological’) approaches to deterrence. Their study, called EMMA (Electroacoustic prototype for controlling the behaviour of Marine Mammals), has used mathematical models and observations of stranded dolphins to identify resonance frequencies for various ‘main’ acoustic organs (e.g. bullae, mandibles, melon), with a view to developing a signal that would cause sufficient discomfort or pain to deter dolphins away from fishing gear.

Ketten cautioned that moderate- to high-intensity received levels in the mid-frequencies have been shown to cause serious trauma (e.g. hemorrhaging) in one group of cetaceans, the beaked whales (Ziphiidae). There is some concern that the traumas may be related to resonance effects but that conclusion is still premature and several mechanisms could be involved. Determining resonance effects from isolated tissues is highly problematic. For example, isolated jaw bones from some species have very distinct resonant responses but they do not respond in the same manner at the same frequencies in an intact head. Similarly, it is inappropriate, for two reasons, to generalize from one species to infer that a particular response is likely in any other species. First of all, resonance frequencies are highly species-specific. Second, the precise mechanisms for non-auditory tissue damage from sound are still unclear for all marine mammals.

4.4. Evaluation of the efficacy of acoustic deterrents in reducing conflicts between dolphins and fisheries

To date, no controlled scientific experiment has been conducted to test the effectiveness of an acoustic device in keeping free-ranging bottlenose dolphins (or other delphinids) away from a food source (e.g. fishing net). Results of some hearing-threshold studies with *Tursiops* in captivity are available, and these may be useful in developing approaches to deterrence. Most experiments and trials of responsiveness to pinger-type signals have been conducted with harbour porpoises, which might be expected to differ in important ways from bottlenose dolphins, given their differences in acoustic repertoire, behaviour and ecology. Goodson emphasized that the results of the ADEPTs study in Sicily, which will be available from the European Commission by the end of 2001, indicate that pinger use can be of some benefit to fishermen in deterring bottlenose dolphins but also that such use may not be economical for Mediterranean small-scale commercial fisheries. He also indicated that his work in progress supports the idea that *Tursiops* and *Phocoena* react to pingers much differently.

4.5. Use of acoustic devices in marine protected areas (MPAs)

The workshop discussed whether special restrictions should be placed on the use of acoustic deterrent devices in marine protected areas (MPAs), in order to ensure that it does not conflict with a given site’s intended purpose. Notarbartolo di Sciara explained that Mediterranean coastal MPAs are often small (only a few km^2), and most have a long history of human presence and use (including fishing and other forms of harvesting). Their *raisons d’être* generally include such things as enhancement of sustainable use and tourism as well as preservation of biological diversity. Typically, an MPA has a very small no-take zone, one or more zones where controlled fishing is allowed and at least one zone in which recreational fishing and other uses by local people are permitted. Local fishing communities often support

MPAs because they give them exclusive fishing rights and therefore exclude other fisheries from the area.

After considerable discussion, the workshop was unable to reach consensus on this topic although it acknowledged that managers of individual MPAs may decide, for their own reasons, to restrict the use of acoustic deterrent devices. Some participants expressed the view that, given the risk of acoustic deterrents excluding dolphins from habitat, this risk should not be taken in MPAs which are at least partly set aside to provide sanctuary to threatened species. Others argued that if the risk to animal health is sufficient to raise concerns about habitat exclusion, then use should be restricted more generally and not just in MPAs. The workshop agreed that an environmental impact assessment process should be in place to evaluate any proposed use of acoustic devices in the marine environment. Such a process would involve a series of steps to be followed before any use was approved. Tregenza suggested that MPAs might be preferred sites for testing or employing non-acoustic 'alternative' approaches (e.g. see 'Stealth fishing' in 4.6, below). It was noted that one of the two field sites of the EC-sponsored ADEPTs study, described above, is an MPA, the Sicilian Egadi Islands Marine Nature Reserve (Chiofalo *et al.*, 2000).

4.6. Alternative approaches to the use of acoustic deterrents

Workshop participants offered a number of suggestions that could be useful in developing new approaches to deterring dolphin depredation. Popper called attention to the analogous situation in which airports have been constructed in the core habitat of birds, leading to various types of conflict. Lessons may be learned from efforts to deter birds from flight paths and landing strips.

Trites noted that dolphin trainers at oceanariums and other facilities often have useful insights on how to influence animal behaviour. He suggested that their counsel be sought as researchers attempt to design approaches to deterrence, including but not limited to acoustic approaches. Trites and several other participants emphasized the value of consulting closely with fishermen and encouraging their involvement.

Würsig called the workshop's attention to the extensive literature on aversion techniques used in terrestrial contexts to resolve similar problems of depredation. He specifically noted the use of bait treated with lithium chloride to condition individual coyotes (*Canis latrans*) against preying on sheep. Ketten pointed out that light might also be considered, whether as a repellent or attractant. The workshop **recommended** that other sensory systems in addition to sound, such as taste and vision, be investigated for their potential in aversive conditioning of dolphins.

Dolphin-watching tourism was also considered. In Italy, a practice called *pescaturismo* has recently been encouraged. It allows tourists to go on-board commercial fishing vessels and engage in recreational fishing, bird- and mammal-watching etc., while the crew carry on their normal fishing activities. In the aforementioned squid fishery near Naples, the Risso's dolphins attracted to the fishing grounds are popular with *pescaturismo* passengers and this has led to a softening in the attitude of fishermen towards the animals. Gazo noted that in the Balearic Islands, dolphins are not consistently present on the fishing grounds. Moreover, their interactions with fishing activities take place mainly at night. These factors would need to be considered in any scheme to incorporate dolphin-watching tourism into a mitigation program.

Although there may be situations in which a changeover from fishing to dolphin-watching tourism would be both practical and acceptable to the fishermen, it must be recognized that in many areas fishing is culturally important. Thus, a complete switch to tourism is likely to be resisted. Also, due regard must be given to ensuring that dolphin tourism is itself carefully regulated so that it does not cause major disturbance to the animals.

In Greece there are ongoing efforts to diversify fishing effort and move the fishing fleets away from areas of conflict with dolphins, as well as to develop new types of traps for catching shrimp in deep waters (Vidoris, pers. comm.).

Tregenza (ICRAM/AHD/INFO 24) outlined a series of steps that might be considered instead of, or in addition to, acoustic deterrence to reduce dolphin interactions with fisheries. The goal would be to increase the time required for dolphins to discover the fishing locations, thus reducing the amount of reinforcement they experience for fishery interactions. This approach, which he labelled 'stealth fishing', included the following elements:

- Boats could leave port at slightly reduced speeds to lessen noise.
- They could travel under power to a point upwind of a desired fishing location.
- They could then travel downwind under small sail for short periods, perhaps carrying out some line fishing on the way. The sail could be a relatively small, loose-footed sail on an unstayed, rotating mast so that it would be easy to furl while the vessel is underway or in port.
- The net could be shot under sail only.
- The net could have a 'floating headrope' instead of traditional floats, which are more reflective to dolphin sonar.
- The visibility and acoustic profile of surface buoyage could be minimised in a variety of ways.
- Return of the vessel to the net after soaking could again use a 'broken power trail', if possible.
- Net hauling could be accomplished by the quietest possible means, e.g. hand hauling, or battery-powered hydraulics.
- Net locations could be moved every day, perhaps using local management measures to organize and implement this.

Among the reasons to expect that 'stealth fishing' might work are that: (a) interruptions in the red mullet fishery near Asinara Island, caused by bad weather, are generally followed by brief periods of reduced dolphin depredation; and (b) there are reports that dolphins sometimes follow the fishing boats to the fishing sites.

Tregenza suggested that effectiveness of the 'stealth' technique could be assessed by a trial involving control boats and observers, the support and advice of several fishermen, and funding for gear changes. It would be important to give the fishermen a sense of ownership of the new strategy. A prize might be offered to the fisherman who makes the highest catch of intact fish, or who achieves some other definition of a successful outcome. He added that fishing vessels under sail could have an aesthetic appeal that adds value to Mediterranean tourism, although this intangible effect would be impossible to quantify or demonstrate.

Consideration should also be given to propeller and engine choices, with a view to making the fishing vessels more difficult for dolphins to find and follow. Dawson noted that water jets over propellers were extremely effective at damping engine noise. Barlow recalled the example of killer whale depredation on longlines in Alaska, which was substantially mitigated by isolating the winch hydraulics, thus depriving the whales of what had been a major acoustic cue ('dinner bell'). Goodson agreed that hydraulic and other noise from the fishing vessels themselves likely played an important role in attracting dolphins to the fishing sites in the Mediterranean. He suggested rubber facing on the haulers as one example of a way to quieten gear in trammel net fisheries. Vidoris suggested that floating rope rather than floats could make setting quieter.

There was some discussion about encouraging fishermen to use larger mesh nets and also about the possibility of using new materials (stronger than nylon) for the netting. In general, however, participants agreed on the need to improve understanding of the process and dynamics of the fisheries, including aspects such as when and how the dolphins detect, follow or intercept the fishing boats. While it was recognized that in an ideal world fishermen would contribute, either individually or collectively, to the costs of solving the problem, it was acknowledged that government agencies should play a role.

Because dolphins have learned to exploit fisheries as a new food source, it will be necessary to either increase the costs or decrease the rewards that come from foraging in nets. Also, if the mere presence of dolphins on the fishing grounds can have a detrimental effect on catch levels, as has been suggested in some instances (e.g. ICRAM/AHD/INFO 17, 21), any deterrent (increase in costs) would need to be experienced at some distance away from the net.

Specifically with regard to aquaculture, Würsig suggested that anti-predator nets made of stiffer plastic could help exclude marine mammals and prevent their becoming entangled. Ace-Hopkins warned that experience with tensioned nets in Scotland led him to be less sanguine about the feasibility of keeping bottlenose dolphins out of enclosures. They were strong and determined enough to lift the netting and penetrate the enclosures.

4.7. Compensation schemes

Compensation for losses to predators has been used as a mechanism for dealing with wildlife-human conflicts in a number of areas, e.g. wolves (*Canis lupus*) in protected areas in Italy, dolphins and fisheries in Croatia. Although there was a brief discussion of compensation mechanisms, participants regarded this management topic as largely outside their expertise. Although fishermen often embrace compensation as a preferred approach to mitigation, any such scheme must be carefully considered, with due regard for human behavioural and psychological implications. The one area in which scientists could play a valuable role would be in helping devise methods of calculating loss.

Amundin called attention to a novel approach in Sweden whereby Lapp reindeer herders are compensated for the numbers of wolverines (*Gulo gulo*) inhabiting their grazing lands, regardless of stock losses and other forms of damage. This more ‘positive’ approach has worked well, as has a similar scheme to encourage fishermen and mariculturists in Sweden to tolerate gray seals. Dawson emphasized that compensation would be most effective when provided to fishermen for changing their fishing methods rather than simply for damages *per se*. He also cautioned against any scheme that pays fishermen not to fish Northridge pointed out the difficulties inherent in measuring damage and administering a compensation scheme. It is important to somehow limit eligibility to a fixed number of fishermen.

It was agreed that an integrated approach to mitigation should be tried, perhaps in an MPA on a ‘pilot’ basis, involving, for example, some combination of *pescaturismo*, compensation and ‘stealth’ fishing, with substantial involvement of fishermen.

4.8. Likelihood of success in reducing negative interactions

Barlow pointed out that although bottlenose dolphins may react to pingers, their reaction may not always be repellence. Rather, they may approach the pinger aggressively (as has been observed in captivity on numerous occasions when dolphins were exposed to novel or annoying sounds; Amundin, pers. comm.), or they may habituate rapidly (e.g. see results a field experiment with harbour porpoises; Cox *et al.* 2001). The waning of responsiveness as animals became either habituated or desensitized has been a consistent trend in the use of AHDs to deter pinnipeds from aquaculture facilities (Reeves *et al.*, 1996). Amundin pointed out, however, that habituation is stimulus-correlated and that if the sound characteristics of a signal are varied, it should be possible to offset or slow down the process of habituation.

During discussion, several participants emphasized that extrapolations from captivity need to be made with caution. For example, an aggressive response by *Tursiops* to a noise source in a tank may be an artifact of confinement. Moreover, responses may depend on an individual’s age and sex, or its behavioural state. In other words, it should not be assumed that an individual dolphin will always respond the same way to a given acoustic (or other) stimulus. It was generally agreed that threshold response studies in captivity are valuable but that observations of overt behavioural responses made in captivity must be qualified appropriately and interpreted cautiously.

Ace-Hopkins suggested that the ultimate solution may lie in development of a method of ‘jamming’ or ‘scrambling’ a dolphin’s sonar. Goodson added that in fact some of the high-frequency energy in certain pingers probably passes through the relevant frequencies in the harmonics of dolphin echolocation signals, and that some of the observed deterrent effect may be due to ‘sonar scrambling’. Amundin disagreed, noting that dolphin sonar is adept at functioning in the midst of a broken or sporadic signal. Further research is clearly needed on how bottlenose dolphins respond to various types of signal.

The workshop **concluded** that the following factors would help determine the success or failure of any effort to reduce negative interactions between dolphins and fisheries by the use of acoustic deterrent devices:

- Presumably, the dolphins are strongly motivated to be around the nets (i.e. they are strongly rewarded).

- The large spatial overlap between trammel and gill net fisheries and the habitat of bottlenose dolphins creates potential for repeated exposure and, thus, habituation (i.e. waning effectiveness of a deterrent over time).
- Bottlenose dolphins use high-intensity, broadband sounds in intraspecific communication; thus they are less likely than, e.g. harbour porpoises, to find these types of sounds aversive.
- Bottlenose dolphins learn rapidly and are behaviourally flexible and adaptable.
- The local depletion of fish stocks, whether real or perceived, may exacerbate conflicts between dolphins and fisheries.
- There is a large gap between what is known about the dolphins and the relevant fisheries in the Mediterranean, and what needs to be known to develop effective, long-term solutions.

Among issues that may be relevant but need further study are that older dolphins may be significantly less sensitive to acoustic deterrents because of hearing impairment, and dolphins may exhibit considerable intraspecific variation in their responses to acoustic stimuli.

5. Major Research Needs

The workshop identified the following major research needs in relation to interactions between dolphins and fisheries in the Mediterranean:

- Obtain information on dolphin population size and structure, and individual ranges.
- Determine identity, age and sex of individuals involved in fishery interactions using photo-identification.
- Identify overlap between fishing activities and the ranges of individual dolphins.
- Investigate behavioural clues used by dolphins to find fishing vessels or nets.
- Map all areas where negative interactions between dolphins and fisheries (including aquaculture) occur ('hotspots').
- Map areas where dolphins and fisheries (particularly gill net and trammel net fisheries) overlap without negative interactions.
- Characterize local fishing techniques in detail (e.g. gear types, grounds, target species, fishing behaviour) for both types of area (with and without negative interactions).
- Promote standardization of methods used to collect, report and interpret data on damage to catch and nets.
- Investigate monk seal hearing and the potential for adverse effects of acoustic deterrents on this highly endangered species.
- Evaluate hearing of target and non-target fish species and other biota.

In an ideal world, a step-wise, sequential approach to research and monitoring would be followed, with experiments and field trials being undertaken only after appropriate background documentation was in place. Such an approach can be outlined as follows:

- Characterize the nature of interactions in a quantitative manner.
- If a problem exists,
- Consult widely and locally for potential solutions; and
  Undertake experimental testing of potential solutions, while carefully

assessing their adverse effects.

- If an experiment is successful,

  Expand the approach and transfer information to equivalent fisheries; and
  Establish a long-term monitoring program to ensure continued efficacy and document unforeseen impacts.

6. Workshop Conclusions and Recommendations

In addition to the **conclusions** highlighted elsewhere in the report, the workshop **concluded** that:

- Acoustic devices have the potential to damage the hearing of dolphins and other animals and to cause other impacts, such as habitat exclusion. However, the effects of acoustic exposure are highly species-specific and depend on each species' frequency sensitivity, and on the received level of the sound. Available data suggest that ultrasonic, low-intensity devices are most likely to be effective for deterring odontocetes while having the least probability of causing harm to other species.

- To evaluate the effectiveness of any mitigation strategy, it is necessary to have clearly stated management goals. At present, these do not exist in relation to fishery-dolphin conflicts in the Mediterranean.

- Very little quantitative information exists on: the nature and extent of interactions between dolphins and small-scale commercial fisheries in the Mediterranean, the costs of such interactions to the fisheries, or the effects of such interactions on dolphin populations.

- Given (a) what is currently known about the physiology and behaviour of bottlenose dolphins, (b) the potential for excluding dolphins from habitat (and consequent implications for the health of local dolphin populations) and (c) the potential for negative effects on monk seals, high-intensity acoustic devices such as those currently marketed as AHDs and used to deter pinnipeds from aquaculture operations are *inappropriate* for use in alleviating conflict between dolphins and fisheries (or aquaculture operations) in the Mediterranean. This conclusion applies irrespective of the potentially high, or even prohibitive, costs of deploying these devices in the Mediterranean context. The workshop **underlined** that the use of AHDs in the Mediterranean may contravene current national and international regulations.

- In the absence of conclusive evidence that low-intensity acoustic devices (pingers) can be effective in reducing the frequency of interactions between dolphins and fisheries, further research on this topic would be useful.

- Non-acoustic means of reducing conflicts between dolphins and fisheries hold considerable promise and deserve detailed evaluation.

In addition to the **recommendations** highlighted elsewhere in the report, the workshop **recommended** that:

- Government agencies and international bodies begin developing and articulating management goals for mitigation of fishery-dolphin conflicts so that it will be possible to make meaningful evaluations of effectiveness.

- Site-specific studies be carried out (simultaneously) focussing on the characteristics of particular fisheries and on the ecology and behaviour of ‘local’ dolphin population(s). More information is needed on which animals are engaged in depredation, e.g. individuals or entire groups; older or younger animals, or both; males or females, or both. Photo-identification studies are essential for obtaining this kind of information and for investigating site fidelity. Use of ‘signature whistles’ to identify individuals involved in fishery depredation in the Mediterranean is unlikely to be practical, at least in the short term.

- Any long-term monitoring program include efforts to investigate and document dolphin mortality, to determine whether fishermen are taking retaliatory measures against dolphins.

7. Literature Cited

Barlow, J., and Cameron, G. 1999. Field experiments show that acoustic pingers reduce marine mammal bycatch in the California drift gillnet fishery. International Whaling Commission, Scientific Committee, Doc. SC/51/SM2.

Bearzi, G. and Notarbartolo di Sciara, G. 1997. Bottlenose dolphins following bottom trawlers in the Kvarnevic (northern Adriatic Sea). ECS 11th Ann. Conf., pp. 202-204.

Bearzi, G., Politi, E. and Quondam, F. 2001. Bottlenose dolphins foraging alongside fish farm cages in eastern Ionian Sea coastal waters. ECS 15th Ann. Conf., p. 50.

Cannas, A., Fadda, D., Lenti, G., Massidda, P. and Pinna, D. 1994. I danni provocati dai delfini alla piccola pesca in Sardegna, (Italia) dati preliminari. *Biol. Mar. Medit.* 1(1):291-92.

Cox, T.M., Read, A.J., Northridge, S. and Donovan, G.P. 1998. Reducing cetacean by-catches: progress with acoustic deterrents. Report of the Workshop, Monaco, 19-20 January 1998. Unpubl. manuscript.

Cox, T.M., Read, A.J., Solow, A. and Tregenza, N. 2001. Will harbour porpoises (*Phocoena phocoena*) habituate to pingers? *J. Cetacean Res. Manage.* 3:xx-xx.

Culik, B.M., Koschinski, S., Tregenza, N. and Ellis, G.M. 2001. Reactions of harbor porpoises *Phocoena phocoena* and herring *Clupea harengus* to acoustic alarms. *Mar. Ecol. Prog. Ser.* 211:255-60.

Diaz Lopez, B., Marini, L. and Polo, F. 2001. Evolution of a bottlenose dolphins population in the northeastern waters of the Sardinia (Italy). ECS 15th Ann. Conf., pp. 23-24.

Gazo, M., Fernandez-Contreras, M.M., Brotons, J.M. and Aguilar, A. 2001. Interactions between bottlenose dolphins and artisanal fisheries in the Balearic Islands: may acoustic devices be a solution to the problem? ECS 15th Ann. Conf., p. 37.

IWC. 2000. Report of the Sub-committee on Small Cetaceans. *J. Cetacean Res.Manage.* 2 (Suppl.):235-63.

IWC. 2001. Report of the Workshop on Bycatch Mitigation Measures in Static Fisheries. *J. Cetacean Res. Manage.* 3 (Suppl.):xx-xx.

Johnston, D.W. and Woodley, T.H. 1998. A survey of acoustic harassment device (AHD) use in the Bay of Fundy, NB, Canada. *Aquatic Mammals* 24:51-61.

Ketten, D.R. 1998. Marine mammal auditory systems: a summary of audiometric and anatomical data and its implications for underwater acoustic impacts. NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-256, 74pp.

Ketten, D.R., Krum, H., Chittick, E., Meriog, C. and Melvin, E. 1999. Acoustic fatheads: parallel evolution of soft tissue conduction mechanisms in marine mammals, turtles, and birds. Invited paper, joint meeting of Acoustical Society of America and European Acoustics Association, Berlin.

Ketten, D.R., Lien, J. and Todd, S. 1993. Blast injury in humpback whale ears: evidence and implications. *J. Acoustic Soc. Am.* 94:1849-50.

Lauriano, G., Notarbartolo di Sciara, G. and Di Muccio, S. 2001. The interaction between bottlenose dolphin and small scale fisheries in the Asinara Island National Park (north-western Sardinia). ECS 15th Ann. Conf., p. 50.

Mazzanti, C. 2001. Dolphins interactions with bottom trawlers in the cetacean sanctuary. ECS 15th Ann. Conf., p. 51.

Mazzola, S., Guerrini, A., Bonanno, A., Patti, B. and Giusto, G.B. 1996. Preliminary study on census data about the interaction between dolphins and fishing activity in the Sicilian fisheries. ECS 10th Ann. Conf., pp. 256-59.

Melvin, E.F., Parrish, J.K. and Conquest, L.L. 1999. Novel tools to reduce seabird bycatch in coastal gillnet fisheries. *Conserv. Biol.* 13:1386-97.

Mitra, S., Koutrakis, E. and Milani, C. 2001. Cetacean interaction with small scale coastal fisheries: implications for conservation and damage limitation. ECS 15th Ann. Conf., p. 39.

Mussi, B., Gabriele, R., Miragliuolo, A. and Battaglia, M. 1999. Cetacean sightings and interactions with fisheries in the archipelago Pontino Campano, southern Tyrrhenian Sea, 1991-1995. ECS 12th Ann. Conf., pp. 63-65.

Northridge, S.P. and Hofman, R.J. 1999. Marine mammal interactions with fisheries. pp. 99-119 in J.R. Twiss, Jr. and R.R. Reeves (eds), *Conservation and Management of Marine Mammals*. Smithsonian Institution Press, Washington, D.C.

Pace, D.S., Pulcini, M. and Triossi, F. 1999. Tursiops truncatus population at Lampedusa Island (Italy): preliminary results. ECS 12th Ann. Conf., pp. 165-69.

Quero, M.E., Chiofalo, G., Datta, S., Di Natale, A., Dremière, P.Y. and Goodson, D. 2000. Interaction between dolphins and artisanal gillnet fishery: methods of fishery and damage sampling. *European Research on Cetaceans* 14:48-54.

Reeves, R.R., Hofman, R.J., Silber, G.K. and Wilkinson, D. 1996. Acoustic deterrence of harmful marine mammal-fishery interactions: proceedings of a workshop held in Seattle, Washington, 20-22 March 1996. NOAA Tech. Memo. NMFS-OPR-10. 70pp.

Ridgway, S.H. and Carder, D. 1997. Hearing deficits measured in some Tursiops truncatus, and discovery of a deaf/mute dolphin. *J. Acoustical Soc. Am.* 101:590-3.

Silvani, L., Raich, J. and Aguilar, A. 1992. Bottle-nosed dolphins, *Tursiops truncatus*, interacting with local fisheries in the Balearic Islands, Spain. *European Research on Cetaceans* 6:32-34.

Tringali, M., Puzzolo, V. and Caltavuturo, G. 2001. A case of opportunistic feeding: the bottlenose dolphin, *Tursiops truncatus*, interference to the European anchovy, *Engraulis encrasicolus*, fishing in the Gulf of Catania (Ionian Sea). ECS 15th Ann. Conf., p. 28-29.

Watkins, W.A. and Schevill, W.E. 1975. Sperm whales (*Physeter catodon*) react to pingers. *Deep-Sea Res.* 22:123-29.

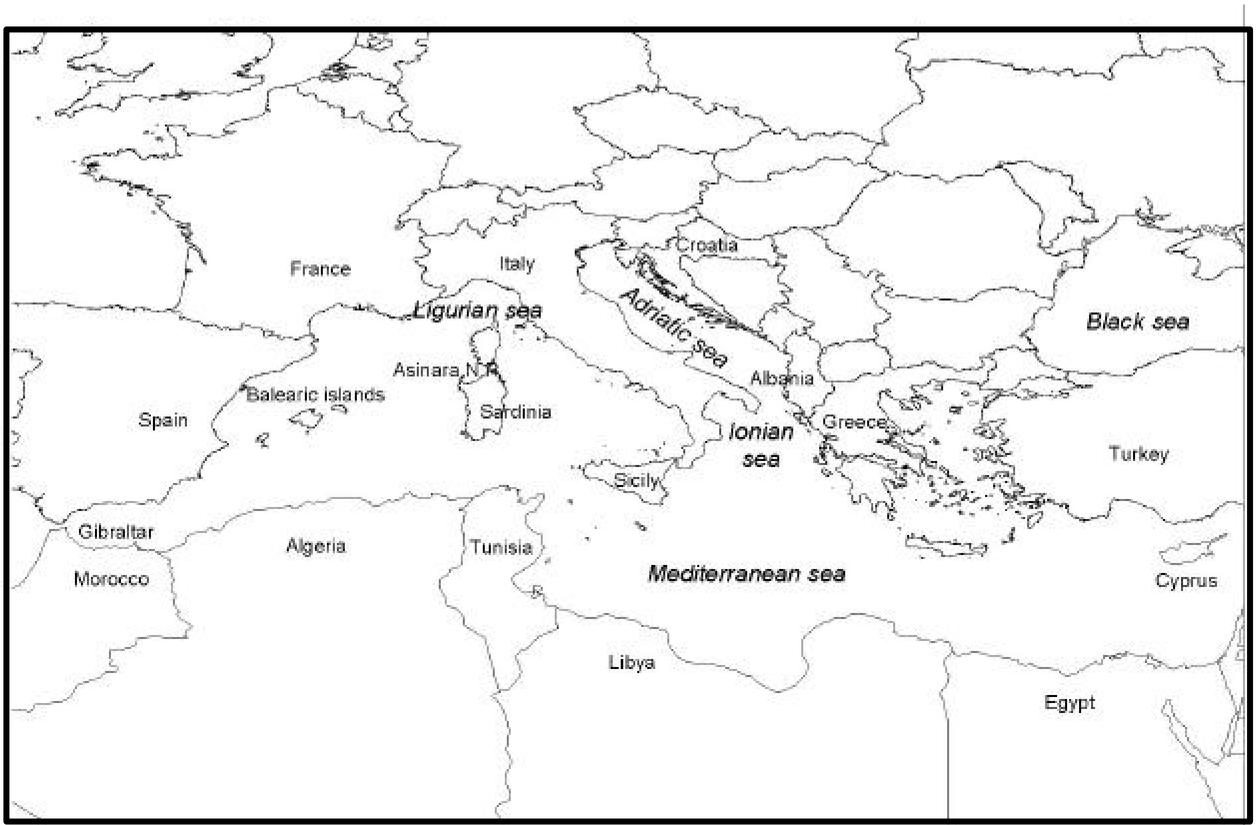

Fig. 1 – Map of the Mediterranean Sea.

Table 1. Characteristics of selected high-intensity acoustic deterrents generally known as Acoustic Harassment Devices, or AHDs. Source: John Ace-Hopkins (pers. comm.); also see Johnston & Woodley (1998).

Name of device	**Freq. (kHz)**	**Source level (dB re 1µPa at 1m)**	**# of hydro phones**	**Pulse groups/hr**	**Pulse group duration**	**Pulse duration**	**Mark : space ratio**
Airmar dB II Plus (‘ringer’)	10 (tonal)	194	4	Nearly continuous	15sec	15sec	N/A
Ferranti-Thomson Mk3 Seal Scrammer (‘multi-tone’)	8-30 (broad-band)	194	1	6	20sec	20msec	0.0424
Silent Scrammer (Ace Aquatec)	8-30 (broad-band)	194	1	2	20sec	20msec	0.0424
Fish Guard	15 (narrow -band)	191	1	60-1020	6sec	500msec	1:1 to 1:4
Terecos	5-15? (centred at 10) (broad-band)	185	1	20 (selectable)	10-20sec	1-2sec	N/A

Table 2. Characteristics of selected low-intensity acoustic deterrents generally known as pingers. ‘C’ = commercially available; ‘H’ = homemade but used extensively in trials; ‘L’ = derivative of Jon Lien’s original design for baleen whales; ‘US’ = emissions specified for regulated US fisheries; ‘DK’ = Type 1 emissions specified for regulated Danish fisheries. Note: PICE? is not listed here as the commercial AQUAmark 100? is an improved derivative which transmits the same wideband randomised acoustic signals. Source: Dave Goodson (pers. comm.).

Manufacturer	Dukane Corp. (C)	Aquatec Sub-Sea Ltd (C)	Fumunda (C)	Lien - L1 (H)
Models	Net Mark 1000? (a); Netmark 2000 (b)	Aquamark 100? (a); Aquamark 200 (b); Aquamark 300 (c)	FMP 332	Gearin (L2); McPherson (L3)
Source level max/min (dB re 1µP at 1m)	150? 130	145	134? 130	132? 110
Battery	4 x ‘AA’ alkaline	1 x ‘D’ alkaline	1 x lithium	4 x PP3 alkaline
Fundamental Frequency	10kHz (US)	(a) 20-160kHz frequency sweeps (DK); (b) similar to ‘a’ but the frequency sweep tuned for dolphins (DK); (c) 10kHz tonal (US)	10kHz (US)	(L1) 2.5kHz; (L2) 3.5kHz; (L3) 3.5 kHz
High-frequency	Yes	Yes	Yes (Barlow);	Yes (sometim

Harmonics			no (Goodson)	es!)
Pulse duration (nominal)	300msec	300msec	300msec	300msec
Inter-pulse period	4sec (regular)	(a, b) 4-30sec (randomi sed); (c) 4sec (regular)	4sec (regular)	<2sec (L1) (regular)
Life (continuous operation)	~ 5 weeks	(a, b) 18 months to 2 years	12 months	3-4 weeks
Wet switch	(a) no, (b) yes	Yes	No	Yes
Battery change	Yes	No (option available soon)	Yes	Yes
Environmental (battery disposal) recycling	None	20% discount for returned units against replacem ents	None	None
Spacing along nets (max. recommended)	100m	200m	100m	<50m

Appendix 1

List of participants

John Ace-Hopkins
Ace Aquatec, Summerlea, Holnest Park, Sherborne, DT9 6HA, UK, tel: +44 (0) 1963-210-455, fax: +44 (0) 1963-210-455, Email: john@aceaquatec.com

Mats Amundin
Kolmardens Djurpark, S-618 92 Kolmarden, Sweden, Phone: +46-11 24 90 18, Mobile phone +46-705 47 04 27, Fax: +46-11 24 90 65, Email: mats.amundin@kolmarden.com, Web site: www.kolmarden.com

Franco Andaloro
Istituto Centrale per la Ricerca Applicata al Mare (ICRAM), Via Emerico Amari 124, 90134 Palermo, Italy, Tel: +39 091 6114044, Fax: +39 091 6114060, http://www.icram.org/, Email : andalorf@tin.it

Alexei Birkun
BREMA Laboratory, R. Luxembourg Str. 27-2a, Simferopol, Crimea 333720, Ukraine, Tel/Fax: + 380 652 253503, Email: alexeibirkun@home.cris.net

Jay Barlow
Southwest Fisheries Science Center (SWFSC), P.O. Box 271, La Jolla, California 92038 USA, email: jbarlow@ucsd.edu

Junio Fabrizio Borsani
Istituto Centrale per la Ricerca Applicata al Mare (ICRAM), Via di Casalotti 300, 00166 Roma, Italy, Tel: +39 06 61570407, Fax: +39 06 61561906, http://www.icram.org/, email: jfaber@tin.it

Steve Dawson
New Zealand Whale and Dolphin Trust, Marine Science Department, Otago University, P.O. Box 56, Dunedin, New Zealand. email: steve.dawson@stonebow.otago.ac.nz, cell. phone (a/h) ++64(25)474-418, office phone: ++64(3)479-7468, Fax: ++64(3)479-8336,
website: http://telperion.otago.ac.nz:800/Marine/mammals/home.htm

Greg Donovan
Editor of the Journal of Cetacean Research and Management, International Whaling Commission, The Red House, 135 Station Road, Impington, Cambridge CB4 9NP, UK, tel: +44 (0)1223 233971, fax: +44 (0)1223 232876, email (personal): greg@iwcoffice.org, web site: http://www.iwcoffice.org

Caterina Fortuna
Istituto Centrale per la Ricerca Applicata al Mare (ICRAM), Via di Casalotti 300, 00166 Roma, Italy, Tel: +39 06 615701, Fax: +39 06 61561906, http://www.icram.org/, email : fortuna.cm@tiscalinet.it

Manel Gazo
Grup d'Estudi i Conservació de Mamífers Marins (GRUMM), Dept. Animal Biology, University of Barcelona, Avgda. Diagonal, 645, 08028 Barcelona – Spain, Tel: +34-93-4034556, FAX: +34-93-4034554, e-mail: manelg@porthos.bio.ub.es

Dave Goodson
Department of Electronic & Electrical Engineering, Loughborough University, Ashby Road, Loughborough, Leicestershire, LE11 3TU, UK, Tel: +44 (0)1509 227076, Email: a.d.goodson@lut.ac.uk, Website: http://sonar-fs.lboro.ac.uk/

Silvestro Greco
Istituto Sperimentale Talassografico (CNR), Spianata S. Raineri, 86, 98122 Messina, Italy, Tel. +39 090/669003, Fax +39 090/669007, E-mail: silviogreco@libero.it, http://www.ist.me.cnr.it/

Dave Johnston
International Marine Mammal Association Inc., 1474 Gordon St., Guelph, Ontario, Canada N1L 1C8, tel: (519) 767-1948, fax: (519) 767-0284, email: djohnsto@imma.org

Pavlos Vidoris
National Agricultural Research Foundation, Fisheries Research Institute (F.R.I.), Nea Peramos, 640 07, Kavala, Greece, tel.: (+30) 594 22691-3, fax: (+30) 594 22222, email: fri@otenet.gr, http://www.pref-kavala.gr/guide/alieyten.htm

Darlene Ketten
Biology Department, Woods Hole Oceanographic Institution, Woods Hole, Harvard Medical School, Department of Otology and Laryngology. MA 02543-1049, USA, Tel: (508) 457-2000, Email: dketten@whoi.edu, Web Site: http://www.whoi.edu

Giancarlo Lauriano
Istituto Centrale per la Ricerca Applicata al Mare (ICRAM), Via di Casalotti 300, 00166 Roma, Italy, Tel: +39 06 615701, Fax: +39 06 61561906, http://www.icram.org/, email : lauriano@tin.it

Antonio Mazzola
Dept. Animal Biology, University of Palermo and Consorzio Nazionale Interuniversitario per le Scienze del Mare (CoNISMa), Via Archirafi, 18, I-90123, Palermo, Italy, Tel: +39 091 6167497-6177159, Fax: +39 091 6172009, email: amazzola@unipa.it

Salvatore Mazzola
Istituto di Ricerche sulle Risorse Marine e Ambiente CNR (IRMA-CNR), Italy, Via Vaccara, 61, 91026 Mazara del Vallo (TP), Italy, tel: +39 0923 948966/934116, fax: +39 0923 906634, Email: mazzola@irma.pa.cnr.it, website: http://www.irma.pa.cnr.it/

Giulia Mo
Istituto Centrale per la Ricerca Applicata al Mare (ICRAM), Via di Casalotti 300, 00166 Roma, Italy Tel: +39 06 615701, Fax: +39 06 61561906, http://www.icram.org/, Email : mogiulia@tin.it

Simon Northridge
Sea Mammal Research Unit (SMRU), Gatty Marine Laboratory, University of St Andrews, St Andrews, Fife, KY16 8LB, U.K., Tel +44 1334 462654, Fax +44 1334 462632, Email: spn1@st-andrews.ac.uk

Giuseppe Notarbartolo di Sciara (Convenor)
Istituto Centrale per la Ricerca Applicata al Mare (ICRAM), Via di Casalotti 300, 00166 Roma, Italy, Tel: +39 06 615701, Fax: +39 06 61561906, http://www.icram.org/, email: disciara@tin.it

Arthur N. Popper
Department of Biology, Director, Neuroscience and Cognitive Science Program, University of Maryland College Park, MD 20742, Phone: (301) 405-1940, FAX: (301) 314-9358, email: ap17@umail.umd.edu,

lab web: www.life.umd.edu/biology/popperlab, NACS Web: www.life.umd.edu/nacs, CEBH web: www.life.umd.edu/nacs

Andrew J. Read, (Chair)
Marine Conservation Ecology, Duke University Marine Laboratory, 135 Duke Marine Lab Road, Beaufort, NC 28516, Phone 252-504-7590, Fax 252-504-7648, Email: aread@duke.edu, http://delphinus.ml.duke.edu/readlab/

Randall Reeves (Rapporteur)
Cetacean Specialist Group of the World Conservation Union – IUCN Species Survival Commission, 27 Chandler Lane, Hudson, Quebec, Canada J0P 1H0, Tel/Fax: +1 450-458-7383, Tel: +1 450-458-6685, email: rrreeves@total.net

Nick Tregenza
Institute of Marine Studies, University of Plymouth, Drake Circus, Plymouth, PL4 8AA, UK, email: nick@chelonia.demon.co.uk, tel + 44 (0)1736 711783, fax + 44 (0)870 0554967, website: http://www.chelonia.demon.co.uk

Andrew W. Trites
Marine Mammal Research Unit, Fisheries Centre, University of British Columbia, 2204 Main Mall, Vancouver, B.C. Canada V6T 1Z4, phone: (604) 822-8181, fax (604) 822-8180, email: trites@zoology.ubc.ca, web Site: http://www.marinemammal.org

Peter Tyack
Biology Department, Woods Hole Oceanographic Institution, Woods Hole, MA 02543-1049, USA, tel: (508) 457-2000, email: ptyack@whoi.edu, web Site: http://www.whoi.edu

Bernd Wursig
Department of Marine Biology, Texas A&M University at Galveston, Galveston, TX 77553-1675, USA, Office phone: (409)740-4413, email: wursigb@tamug.tamu.edu,
Web Site: http://www.marinebiology.edu/

Observers

Paolo Pelusi
Consorzio Mediterraneo Legapesca, Via Nazionale, 243, 0184 Roma, Italy, tel.:+39 064620471, fax:+39 0646204723-4, email: legapesca@mclink.it

Giovanni Torchia
SPA/RAC, Centre International de l'Environnement, Boulevard de l'Environnement, PB 337 CEDEX 1080 Tunis – TUNISIA, tel: +216 1 795 760, fax: +216 1 797 349, email: car-asp@rac-spa.org.tn

Marie-Christine Van Klaveren
ACCOBAMS Secretariat, 16, Boulevard de Suisse, MC - 98 000 MONACO, tel: +377 93 15 80 10 Fax: +377 93 50 95 91, e-mail: mcvanklaveren@gouv.mc, website: http://www.accobams.mc

Appendix 2

AGENDA

1 Welcome, introductions and review of meeting objectives, arrangements & agenda

2 Current conflicts between dolphins and fisheries, with an emphasis on the Mediterranean Sea
- 2.1 Identification of interacting dolphins and fisheries
- 2.2 Nature and geographic scope of interactions
- 2.3 Quantification of economic effects on fisheries
- 2.4 Quantification of effects on dolphin populations

3 Overview of acoustic harassment devices
- 3.1 Characterization of acoustic features
- 3.2 Review of uses of AHDs with marine mammals
  - 3.2.1 Applications with commercial fisheries
  - 3.2.2 Applications with mariculture operations
  - 3.2.3 Other applications
- 3.3 Documented and/or potential effects on dolphins
  - 3.3.1 Physiological effects
  - 3.3.2 Behavioural effects
- 3.4 Documented and/or potential effects on other biota
  - 3.4.1 Other cetaceans
  - 3.4.2 Monk seals
  - 3.4.3 Fish
  - 3.4.4 Other

4 Current use of AHDs in Mediterranean
- 4.1 Identification of specific fishery conflicts in which AHDs are being used
- 4.2 Goals of current applications
- 4.3 Existing evaluations of current applications

5 Evaluation of the efficacy of AHDs to reduce conflicts between dolphins and fisheries
- 5.1 Likelihood of meeting management goals
- 5.2 Potential harmful effects on dolphins or other non-target biota
- 5.3 Potential effects on target species

6 Identification of alternative approaches to use of AHDs
- 6.1 Changes in fishing technology or strategies
- 6.2 Compensation mechanisms
- 6.3 Other approaches

7 Recommendations
- 7.1 Monitoring schemes
- 7.2 Future research
- 7.3 Mitigation of conflicts between dolphins and fisheries

8 Procedure for reviewing draft meeting report and presentation to ECS and IWC.

Appendix 3

Quantifying Damage to Fisheries by Dolphins

Prepared by Simon Northridge and Giancarlo Lauriano

Perceptions of conflicts are difficult to judge without an objective assessment of the situation. It is important that a statistically valid assessment of any perceived conflict be conducted by independent researchers rather than relying simply on the strength of feeling of fishermen.

Quantifying the level of damage in a fishery requires a carefully planned research programme that takes account of spatial and temporal variability and statistical power. It is important initially to gain a good understanding of how a fishery operates, not least so that the study design can be appropriately stratified. Most sampling will require on-board observations by data collectors (observers) who are independent of the fishery.

There are four notional categories of potential damage, including: damage to nets, damaged fish in nets, fish removed from the nets and reduced catch rates. It is necessary both to *attribute* specific damage to a specific predator (such as a dolphin) and to *quantify* that damage. Linking damage types to dolphins can be accomplished either directly by observation (using underwater video or other imaging techniques, for example) or indirectly by the correlation of a specific type of damage with the presence of dolphins. The former is preferable but not always practicable.

Damage to nets

As with all types of damage, it is necessary to attribute the causes of damage accurately and to characterise and measure the extent of the damage. Ideally, each type of net damage would be attributed to a specific cause, but in reality this is rarely possible. Torn nets, in particular, can be caused by animals actively swimming through or tearing the nets, by other human activities (trawling, anchor setting) or by contact with underwater objects including rocks and debris, and the resulting damage types may be indistinguishable. Some kinds of damage are most likely to occur while the net is being hauled, and such damagemight be monitored by checking (with divers or by a remote video camera) a sample of nets while they are still fishing, immediately prior to hauling and again after hauling. This would probably be useful in areas where significant net damage is being caused by rocks or other impediments during hauling.

Attributing causes to specific types of net damage

- Measure damage that occurs when dolphins are present vs. when they are absent.
- Use video or other imaging techniques to *verify* causes of damage during fishing.
- Check damage (with video or divers) immediately prior to hauling to estimate damage levels due to hauling.

Quantifying the damage

- Count and label torn net sections (possibly using a colour-coded system) either during each haulback or afterwards at dockside, using either the whole net or a (randomised) sample of the total string. Not all types of damage necessarily need to be recorded: 'damage' might be confined to holes more than a minimum size. Temporary repairs should be avoided as these parts of the net are likely to become damaged again and confound attempts to assess cumulative damage.
- Grade damage by costs (note that not all damage needs to be fixed).
- Ensure that net type and characteristics, depth, seabed type and weather conditions are also recorded as all of these may influence damage levels.

Damaged fish in nets

Characterise types of fish damage.

Attributing causes to damaged fish

- Compare the occurrence of particular types of damaged fish during fishing operations when dolphins are or are not present.
- Use video to characterise types of damage, possibly by 'seeding' nets with a high density of fish.

When types of damage can be attributed to individual predatory species, a photographic catalogue of such damage types should be maintained to assist future studies in making attributions.

Quantifying the damage

- Count and characterize damaged fish, by category, during or after hauling.
- If appropriate, grade the damage by severity or proportional financial loss.

Fish being removed from the nets

Look for evidence of fish 'theft'. This could be manifest either by reduced catch rates when dolphins are present, or by physical evidence of fish having been removed.

Identifying the cause of lost fish

- Correlate fish-loss evidence with presence/absence of dolphins.
- Use cameras, remote- or trigger-operated, to identify predator(s) responsible.

Measuring fish removal

- Seed the net with known numbers of identifiable fish and count the number left at regular intervals using divers or video.
- Measure catch-per-unit-effort when dolphins are present and absent – but needs to be considered along with the possibility that dolphins scare fish from the vicinity of the net before they are caught (see below).

Reduced catch rates

Fish may be frightened away from nets by dolphins either feeding in the area generally (for example, dispersing fish schools), or by dolphins chasing fish along or around the nets. To address this, one might:

- Measure the catch-per-unit-effort in the presence and absence of dolphins; consider net length, soak time and the number/weight of fish caught.
- Use automated click detectors (or visual observations) to log the presence of dolphin before, during and after fishing to help determine whether dolphins are attracted to the area by the fishing activity, or the fishing activity happens to coincide with their usual feeding area.

General comments

In all of the foregoing examples, the presence or absence of dolphins could be assessed visually or acoustically. The number of animals and the duration of their presence might be recorded, or in the case of acoustic detection, the number of clicks recorded could be used to investigate correlations with any of the damage measures mentioned above. VHF sonar may be of some use in understanding the behaviour of dolphins around fishing nets.

It would also be sensible while conducting any assessment to observe and record the behaviour of the animals involved, as this might lead to further investigations that help alleviate the problem. Contemporaneous photo-identification studies may help determine whether one, few or many animals are involved. In some cases, recordings of dolphin sounds, with a view to establishing a catalogue of signature whistles, could prove useful.

Surveys may be used to estimate the size and range of the dolphin population(s) involved in the fishery interactions.

Although the use of underwater video or divers is the best way to characterise the causes of any sort of damage, and any visual records of such rare-event interactions would certainly be useful, poor visibility is a limiting factor in many fishing areas. In such areas a correlative approach may be the only viable option for linking damage to predator behaviour.

Estimating financial loss

Reduced catch rates can be converted to currency loss in a straightforward manner. Damaged fish can either be counted as 'lost' entirely, or given a value based on the extent of damage (some damaged fish of larger species can still be marketed). It is more difficult to estimate the economic loss of damaged nets. Care should be taken to ensure that net damage is costed only when the fisherman would actually repair it rather than continuing to fish without bothering to make repairs. Repaired netting might be colour-coded so that temporary or sloppy repair jobs can be detected. Cumulative net damage may reduce the lifetime of a net. This would be very difficult to estimate and net damage costs are always likely to be inaccurate.

The significance of economic loss depends in part upon the ratio of the loss to the total earnings of the fishermen involved. This, in turn, depends upon market price fluctuations and fish supply to the market. If fish prices decline in real terms, or if catch-per-unit-effort declines over a period of time, then an underlying level of damage by dolphins may become increasingly significant to the fishermen. It would therefore be useful to examine trends in landings, trends in market values of fish and trends in costs over a number of years, and also to gain an understanding of the various capital investments that have been made in the fishery, in order to assess what, if any, other factors might be contributing to the perception of conflict.

Appendix 4

Fish Hearing

Arthur N. Popper

Sound Detection by Fishes

Fishes use sound for a wide range of activities that extend from communication and prey detection, to obtaining an overview of the environment that extends well beyond their visual range (e.g. in dark or murky waters) (e.g. Popper and Fay, 1999; Zelick *et al.*, 1999). Behaviour studies have shown that many species of fish can hear (e.g. Fay, 1988; Schellart and Popper, 1992). While data are available for only a few of the 25,000 or more extant species, evidence suggests that most commercially important marine fishes can detect sounds from below 50Hz to perhaps 1kHz. A number of marine species, including clupeids and gadids, are likely capable of detecting sounds to several kHz, and a few clupeids detect sounds to almost 200kHz (e.g. Mann *et al.*, 1997, 1998, 2001). It should be noted that hearing data are not available for red mullet (*Mullus surmuletus*) and a number of other commercially important Mediterranean species.

The hearing range of most fish species other than the aforementioned clupeids is well below the frequency of current acoustic deterrent devices. Thus, in most cases, the impacts of such devices on fish are likely to be very low. However, as new acoustic deterrent devices are developed, and in the case of those species with hearing thresholds higher than a few kHz, the sounds produced by these devices may have an impact.

Behaviour studies have also shown that at least one species of fish has temporary loss of hearing after being presented with loud, short-duration sounds at about 400Hz (Popper and Clark, 1976). While it is hard to extrapolate these data to other species, the results strongly suggest that impacts on fish hearing are broadly similar to those on the hearing of other vertebrates.

Additional studies have shown that presentation of intense sounds (in the range of 200 to perhaps 800Hz) for several hours are potentially able to kill sensory cells of the ear, thereby strongly affecting the ability of fish to hear (e.g. Enger 1981; Hastings *et al.*, 1996). While it is possible that these cells will regenerate over time (Lombarte *et al.*, 1993), the loss of sensory cells, even if only temporary, could influence survival of the affected animals. Again, however, it must be emphasized that extrapolation from the data for a few species to all others is very difficult and must be done only with *extreme* caution. While these studies must be replicated, they do lead to concern that long-term exposure to sounds may have an impact on fishes.

While the impact may not be as great on free-ranging fishes that are able to move away from sound sources, there may be a somewhat larger impact on fishes kept in mariculture facilities where they receive long-term exposure to sounds emitted by an acoustic deterrent device. This assumes, of course, that the species can detect the signals produced by the device. While one might argue that the non-continuous nature of the sounds, even though they are detectable, means that impact on the ear would not be significant, there is also the potential that long-term exposure could raise stress levels in the fish, with consequent impacts on growth and reproduction.

Other Species

In addition to fishes, other marine organisms may be able to detect sound, although there are no data to show how they respond to it, or whether current acoustic deterrent devices operate in frequency ranges that could affect such species. Sharks, for example, are able to detect sounds to about 1kHz, although data are very limited and there is variability between species (e.g. Banner, 1972; Fay, 1988). It is important to note that sharks are *attracted* to pulsed low-frequency sounds (100-200Hz) (Myrberg *et al.*, 1974; Nelson and Johnson, 1976)).

Turtles have a well-developed ear. However, nothing whatsoever is known about how they use sound. They may 'listen' to their environment, as has been suggested for fish. Data on hearing abilities of turtles are extremely limited. A few studies, using a variety of species and techniques, suggest that those turtles studied have poor hearing sensitivity and a narrow range of hearing (perhaps from below 100Hz up to 800Hz) (reviewed in Dooling *et al.*, 2000). However, considering how few data there are, it would be ill-advised to reach any conclusions about the potential effects of acoustic deterrent devices on turtles until many more studies are completed.

Even fewer data are available on hearing by invertebrates, including cephalopods and crustaceans. One study suggests that the American lobster (*Homarus americanus?*) can hear, but this needs replication. Cephalopods have a well-developed statocyst that has many characteristics in common with the ears of vertebrates. It is possible to determine, with the right experiments, whether some of these species can detect some sounds.

Research Topics

Hearing capabilities (especially range) of commercially important fishes in the Mediterranean.

Impact of high-intensity sounds (within hearing range) on structure of the ear and hearing in marine species and in species used in mariculture.

Effect of high-intensity sounds (within hearing range) on stress levels in marine fishes.

Response characteristics of clupeids and gadids to ultrasonic acoustic deterrent devices, with the goal of designing sounds that are detectable by dolphins but not by other ultrasound-detecting species.

Determination of hearing capabilities of selected invertebrates, including cephalopods of commercial importance. If they hear, there would be a need to determine whether they can detect acoustic deterrent devices, and then to investigate how they respond to such sounds.

References

Banner, A. (1972). Use of sound in predation by young lemon sharks, *Negaprion brevirostris* (Poey). *Bull. Mar. Sci.*, **22**, 251-283.

Dooling, R. J., Lohr, B., Dent, M. (2000). Hearing in birds and reptiles. In: Dooling, R. E., Fay, R. R. and Popper, A. N. (eds). (2000). *Comparative Hearing: Reptiles and Birds*. Springer-Verlag, New York.

Enger PS (1981) Frequency discrimination in teleosts - central or peripheral? In: Hearing and sound communication in fishes (Tavolga WN, Popper AN, Fay RR, eds), pp 243-255. New York: Springer-Verlag.

Fay, R. R. (1988). *Hearing in Vertebrates, A Psychophysics Databook*. Hill-Fay Assoc., Winnetka, Ill.

Hastings, M. C., Popper, A. N., Finneran, J. J. and Lanford, P. J. (1996). Effect of low frequency underwater sound on hair cells of the inner ear and lateral line of the teleost fish *Astronotus ocellatus*. J. Acoust. Soc. Am., 99:1759-1766.

Lombarte, A. Yan, H.Y., Popper, A.N., Chang, J.C., and Platt, C. (1993). Damage and regeneration of hair cell ciliary bundles in a fish ear following treatment with gentamicin. Hear. Res., 66:166-174.

Mann, D.A., Lu, Z., and Popper, A.N. (1997). Ultrasound detection by a teleost fish. Nature, 389:341.

Mann, D. A., Lu, Z., Hastings, M. C. and Popper, A. N. (1998). Detection of ultrasonic tones and simulated dolphin echolocation clicks by a teleost fish, the American shad (*Alosa sapidissima*). J. Acoust. Soc. Am., 104:562-568.

Mann, D. A., Higgs, D. M., Tavolga, W. N., Souza, M. J., and Popper, A. N. (2001). Ultrasound detection by clupeiform fishes. J. Acoust. Soc. Am. in press.

Myrberg, A.A. Jr., Gordon, C.R. & Klimley, A.P. (1976). Attraction of free ranging sharks by low frequency sound, with comments on its biological significance. Sound Reception in Fish. A. Schuijf and A.D. Hawkins, eds. pp. 205-228.

Nelson, D. R., Johnson, R. H.(1976) Some recent observations on acoustic attraction of Pacific Reef sharks. In Sound Reception in Fish. Schuijf, A., Hawkins, A. D. (eds.). Amsterdam: Elsevier, pp. 229-239.

Popper, A.N., and Clarke, N.L. (1976). The auditory system of the goldfish (*Carassius auratus*): Effects of intense acoustic stimulation. Comp. Biochem. Physiol., 53A:11-18.

Popper, A. N., and Fay, R. R. (1999). The auditory periphery in fishes. In: Fay, R. R. and Popper, A. N. (eds.) *Comparative Hearing: Fish and Amphibians*, Springer-Verlag, New York, pp. 43-100.

Schellart NAM, Popper AN (1992) Functional aspects of the evolution of the auditory system of actinopterygian fish In: The evolutionary biology of hearing (Webster DB,Fay RR, Popper AN, eds), pp 295-322. New York: Springer-Verlag.

Zelick, R., Mann, D., and Popper, A. N. (1999). Acoustic communication in fishes and frogs. In: Fay, R. R. and Popper, A. N. (eds.) *Comparative Hearing: Fish and Amphibians*, Springer-Verlag, New York, pp. 363-411.

Appendix 3

List of Information and Background Documents

Please note: documents listed below should be requested directly from the author(s).

Sound and Non-Mammalian Marine Vertebrates. A.N. Popper	ICRAM/AHD/INFO 1
Management of gillnet bycatch of cetaceans in New Zealand. S. Dawson	ICRAM/AHD/INFO 2
Pingers are Acoustic Harassment Devices. R.C. Anderson, J. Barlow, A.E. Bowles	ICRAM/AHD/INFO 3
Some recent and ongoing work on pingers using porpoise click loggers (PODs). N. Tregenza	ICRAM/AHD/INFO 4
Marine Mammals and Aquaculture: Conflicts and Potential Resolutions. B. Würsig & G.A. Gailey	ICRAM/AHD/INFO 5
European Programmes	ICRAM/AHD/INFO 6
EPIC – Elimination of Harbour Porpoise Incidental Catches	ICRAM/AHD/INFO 7
Silent Scrammer Trials - Summary Report. J. Ace-Hopkins	ICRAM/AHD/INFO 8
A brief summary of the effects of acoustic harassment devices (AHDs) on harbour porpoises (*Phocoena phocoena*) in Canada. Exclusion distances and theoretical zones of influence. D. Johnston	ICRAM/AHD/INFO 9
A Proposed Methodology To Quantify Underwater Acoustic Pollution. J. Ace-Hopkins	ICRAM/AHD/INFO 10
Agreement on the Conservation of Cetaceans of the Black sea, the Mediterranean sea and the contiguous Atlantic area. M.-C. Van Klaveren	ICRAM/AHD/INFO 11
Agreement on the Conservation of Cetaceans of the Black sea, the Mediterranean sea and the contiguous Atlantic area. Signature and ratification M.-C. Van Klaveren	ICRAM/AHD/INFO 12
Acoustic deterrents for bycatch mitigation. A. Smerdon	ICRAM/AHD/INFO 13
Reactions of harbor porpoises *Phocoena phocoena* and herring *Clupea harengus* to acoustic alarms. B.M. Culik, S. Koschinski, N. Tregenza, G. M. Ellis. Marine Ecology Progress Series 211:255-260, 2001.	ICRAM/AHD/INFO 14
Experimental Attempts to Reduce Predation by Harbor Seals on Out-Migrating Juvenile Salmonids. H. Yurk & A. W. Trites. *Transactions of the American Fisheries Society* 129:1360–1366, 2000.	ICRAM/AHD/INFO 15
Will harbour porpoises *(Phocoena phocoen*a) habituate to pingers? T.M. Cox, A.J. Read, A. Solow, N. Tregenza*. J. CETACEAN RES. MANAGE.* 3(1):000–000, 2001.	ICRAM/AHD/INFO 16
Interactions between bottlenose dolphins and small scale fisheries in the Asinara Island National Park (north-eastern Sardinia). G. Lauriano. NOTES	ICRAM/AHD/INFO 17
The EPIC project. A progress report, April 1999. Mats, A., Deportes, G., Goodson, D., Teilmann, J.	ICRAM/AHD/INFO 18
Developing deterrent devices designed to reduce the mortality of small cetaceans in commercial fishing nets. Goodson,A.D .	ICRAM/AHD/INFO 19
Acoustic Deterrents to Eliminate Predation in Trammel - nets (ADEPTS)	ICRAM/AHD/INFO 20
Project ADEPTs and EC DG XIV funded study	ICRAM/AHD/INFO 20a
Interactions between bottlenose dolphins and small scale fisheries in the Asinara Islan National Park (north-eastern Sardinia). Lauriano, G., Di Muccio, S., Cardinali, A. &	ICRAM/AHD/INFO 21

Notarbartolo di Sciara, G.

A survey on acoustic harassment device (AHD) use in the Bay of Fundy, NB, Canada. Johnston, D.W., Woodley, T.H.	ICRAM/AHD/INFO 22
Aquatec, Aquamark, Acoustic Marine Mammal Deterrents	ICRAM/AHD/INFO 23
Stealth Fishing – an alternative mitigation approach. Tregenza, N.	ICRAM/AHD/INFO 24
Interactions between bottlenose dolphins and artisanal fisheries in the Balearic island. Gazo, M.	ICRAM/AHD/INFO 25
Acoustic harassment device (AHD) use in the aquaculture industry and implications for marine mammals. Taylor, V.J., Jonhston, D.W., Verboom, W.C. 1997. Proceedings of the Institute of Acoustics 19(9):267--275.	ICRAM/AHD/INFO 26

Background Documents (not distributed – for consultation only)

- Marine mammal auditory system: a summary of audiometric and anatomical data and its implications for underwater acoustic impacts. Ketten, D. 1998. Noaa Technical Memorandum NMFS 256.

- Addressing Incidental Mortalities of Harbour Porpoise *(Phocoena phocoena)* in Groundfish Fisheries of Atlantic Canada. Woodley, T.H. 1995. International Marine Mammal Association Inc. Technical Report No. 95-02.

- Study to investigate the extent and nature of the fixed-net fishery in Hebridean waters and possible conflicts with harbour porpoise *(Phocoena phocoena)* populations. Gill, A. 1999. Report to the Prince Bernhard Fund for Nature.