Mar. Fresh. Behav. Physiol., Vol. 30, pp. 125–146
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BIOACOUSTICS: A TOOL FOR THE CONSERVATION OF CETACEANS IN THE MEDITERRANEAN SEA

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(Received 31 July 1995; In final form 24 June 1996)

Massive human presence in the Mediterranean and inadequate management of marine resources have recently become a threat to marine mammal survival in this region. The main problems facing cetaceans in the Mediterranean include: by-catch in fisheries competition with artisanal coastal gillnet fisheries, presence of noxious manmade, compounds in the trophic chains, and finally, a generalised degradation of environmental quality, particularly evident over the continental shelf, caused by loss of biodiversity, depletion of living resources, increased human disturbance, and changes in the physical and chemical properties of the environment. Conserving cetaceans in the Mediterranean is a modern challenge: appropriate management schemes and pollution control measures should enable marine mammals to coexist with intense human activities, and the Mediterranean could provide an excellent testing ground for such an enterprise. Recent developments in the field of marine bioacoustics could provide information highly relevant to the conservation of cetaceans in the Mediterranean Sea: acoustic surveys can be performed to monitor the distribution and relative abundance pelagic species, and to investigate habitat partitioning of coastal species. Analysis of distinctive vocalisations can indicate the likelihood of links between Mediterranean an Atlantic populations. Finally, acoustics can play a major role in solving problems posed by interactions between cetacean and fisheries, in monitoring the effects of high-intensity acoustic deterrents, and to understand the possible negative effects of some manmade noise on cetacean populations.

Keywords: cetaceans; acoustics; Mediterranean Sea; conservation

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INTRODUCTION

In recent years field studies of Mediterranean cetaceans have increased significantly (*e.g.* Cagnolaro and Notarbartolo di Sciara, 1992; Bearzi *et al.*, 1992; Marini *et al.*, 1992; Notarbartolo di Sciara *et al.*, 1993; Forcada *et al.*, 1994; Relini *et al.*, 1994; Borsani and Pavan, 1994; Forcada *et al.*, 1995; Forcada *et al.*, in press). These have revealed that in many areas these mammals are relatively abundant and accessible to scientific investigation. The Mediterranean environment is particularly amenable to observational studies of cetacean ecology, behaviour and population levels owing to its often favourable meteorological conditions. In addition, members of its simplified cetacean fauna (Notarbartolo di Sciara, 1993a) are easy to distinguish and to identify, both visually (Notarbartolo di Sciara *et al.*, 1993) and acoustically (Borsani and Pavan, 1994).

However, cetaceans in the Mediterranean face a large number of threats (Anon., 1992a) which are jeopardising their continued existence in this region. This has raised considerable international concern, and stimulated the proposal and adoption of an Action Plan for the Conservation of Cetaceans in the Mediterranean Region by the Contracting Parties to the Barcelona Convention (Anon., 1992b), and the drafting of an Agreement on the Conservation of Cetaceans of the Mediterranean and the Black Seas and Contiguous Waters by the Secretariat of the Bonn Convention.

Conserving Mediterranean cetaceans can be considered an important challenge of our times. If coexistence of marine mammals with humans can be achieved in the Mediterranean, a semi-enclosed marine basin where human influence and activities are extreme, it should give us hope that marine mammal conservation problems can be solved in the future on a global scale.

One of the first difficulties encountered in the attempts to solve Mediterranean whale and dolphin conservation problems is a lack of adequate knowledge of population distribution, size, discreteness, trends, and dynamics for any of the cetacean species. Very little is known concerning migratory habits, habitat needs, preferences, and suitability. Furthermore, the structure of the principal ecosystems important for Mediterranean cetaceans, including their trophic relationships and the interdependence of species, is still poorly understood.

The aim of this paper is to describe how some bioacoustic methods could be used to help conserve the marine environment. We suggest that studies of cetacean populations living in the Mediterranean Sea, largely based on acoustic methods and techniques, could significantly contribute to a better understanding of these mammals' ecology and thus help improving their conservation status.

THE MEDITERRANEAN CETACEANS: AN OVERVIEW

In total, 19 cetacean species have been recorded from the Mediterranean Sea (Notarbartolo di Sciara and Demma, 1994). Eight of these are regularly found in the region: one mysticete (fin whale, *Balaenoptera physalus*), and seven odontocetes (sperm whale, *Physeter catodon*; Cuvier's beaked whale, *Ziphius cavirostris*; long-finned pilot whale, *Globicephala melas*; Risso's dolphin, *Grampus griseus*; bottlenose dolphin, *Tursiops truncatus*; striped dolphin, *Stenella coeruleoalba*; and common dolphin, *Delphinus delphis*) (Notarbartolo di Sciara and Demma, 1994).

General cetacean abundances in the Mediterranean are supposedly higher west of the Italian peninsula than in the eastern basin (Marchessaux, 1980; Notarbartolo di Sciara, 1993a), although quantitative comparative surveys have never been conducted. Reviews of cetacean distribution abund for the western (Duguy and Cyrus, 1973; Casinos and Vericad, 1976; Casinos and Fillela, 1977; Duguy *et al.*, 1983b; Raga *et al.*, 1985; Viale, 1985; Bayed and Beaubrun, 1987; Gannier and Gannier, 1992; Notarbartolo di Sciara *et al.*, 1993; Notarbartolo di Sciara, 1994) and the central portions of the Mediterranean (Brusina, 1889; Ktari-Chakroun, 1980; Bello, 1990; Marini *et al.*, 1992; Politi *et al.*, 1992; Notarbartolo di Sciara *et al.*, 1993; Notarbartolo di Sciara and Bearzi, 1993). However, the literature covering the eastern basin is very sparse (Marchessaux, 1980). The species regularly found in the Mediterranean have been classified into three categories based on their habitat preferences. These are: pelagic (fin whale, pilot whale, Cuvier's beaked whale, and striped dolphin), slope (sperm whale and Risso's dolphin), and coastal (bottlenose and common dolphin) (Notarbartolo di Sciara, 1993b; Notarbartolo di Sciara *et al.*, 1993). Bottlenose dolphins are occasionally found in coastal lagoons (Parona, 1908; Rallo, 1976) and estuaries. Absolute population abundance estimates obtained through line transect surveys have been obtained for western Mediterranean striped dolphins, with a calculated population size of 117,880 individuals (Forcada *et al.*, 1994), western Mediterranean fin whales (3,583 indiv.) (Forcada *et al.*, in press), and Corsican-Ligurian Basin striped dolphins (25,614 indiv.) and fin whales (901 indiv.) (Forcada *et al.*, 1995). All these population estimates were conducted in the summer months. Population levels could differ dramatically in other seasons due to possible migrations of the species involved. Relative frequencies of sightings have been determined for the seas surrounding Italy (Notarbartolo di Sciara *et al.*, 1993), for the central Tyrrenian Sea (Marini *et al.*, 1992), and for the waters adjacent to the Greek Ionian islands (Politi *et al.*, 1992). These data indicate that striped dolphins and fin whales predominate in pelagic waters, bottlenose dolphins in coastal waters.

MAIN PROBLEMS ENCOUNTERED BY CETACEANS IN THE MEDITERRANEAN

The threats to cetacean survival in the Mediterranean Sea all derive from these mammals' interactions with human activities or from human-induced modifications to the marine environment. The main problems are caused by: a) interactions with fishing activities, b) pollution, and c) habitat degradation.

Fisheries Interactions

In pelagic waters, the major cause of cetacean mortality deriving from fishing activities is the accidental entanglement in driftnets of many species, including (in order of decreasing numbers): striped dolphins, sperm whales, common dolphins, bottlenose dolphins, long-finned pilot whales, Risso's dolphins, Cuvier's beaked whales, and fin whales (Podestà and Magnaghi, 1989; Notarbartolo di Sciara, 1990; Aguilar and Silvani, 1994; Di Natale and Notarbartolo di Sciara, 1994). Bycatch numbers are unknown, but it is clear (Anon., 1994) that they exceed 'the safe take limit' of 2% for the population of approximately 118,000 striped dolphins estimated to be in the western Mediterranean (Forcada *et al.*, 1994). Bycatch mortality is thus unsustainable for striped dolphins, and could also be depleting populations of sperm whales (Anon., 1994).

In coastal waters the widespread use of small-scale artisanal bottom gillnets, which may result in mortality of coastal species such as the common dolphin and the bottlenose dolphin (Di Natale and Notarbartolo di Sciara, 1994), is a significant problem. Bottlenose dolphins in the Mediterranean are known to damage artisanal fine-mesh gear and take fish from nets (Consiglio *et al.*, 1992; Cannas *et al.*, 1994). This can provoke human hostility that often leads to directed mortality (Duguy *et al.*, 1983a; Silvani *et al.*, 1992; Di Natale and Notarbartolo di Sciara, 1994), or to active attempts of displacing the dolphins from the fishing areas using high-intensity sound emissions (Mhenni, 1993).

Pollution

Mediterranean cetaceans, because of their longevity and elevated position in marine food webs, usually carry high concentrations of manmade xenobiotics in their tissues (Anon., 1992a). The main pollutant categories include trace elements (Viale, 1978; Capelli *et al.*, 1989; Focardi *et al.*, 1992) and organochlorine compounds such as DDTs and PCBs (Alzieu and Duguy, 1979; Aguilar, 1989; Focardi *et al.*, 1992). Significant differences in the mean concentration of both mercury and organochlorines were found between sub-cutaneous blubber biopsies of two free-ranging pelagic species in the Ligurian Sea, the striped dolphin and the fin whale, the former carrying levels greater by approximately one order of magnitude (Focardi *et al.*, 1992). Such differences are likely to be due to the different positions occupied by the two species in the pelagic trophic web.

Coastal species, such as bottlenose dolphins, are exposed to even greater pollutant loads. Total PCB values in the liver of a bottlenose dolphin found stranded in the Adriatic Sea reached the extraordinary level of 745 ppm on lipid basis (L. Marsili, pers. comm.). It has been suggested that cetaceans accumulate extremely high concentrations of toxic organochlorine contaminants due to their low metabolic ability to degrade these compounds (Tanabe *et al.*, 1988). This is further corroborated by MFO activity data obtained from Mediterranean fin whales and striped dolphins (Fossi *et al.*, 1992). Although conclusive information on the effects of these pollutants at the level of populations is lacking, it is well known that organochlorines depress reproductive rates, alter skeleton development, cause cancer, hypertension, stroke and depress the immune system of mammals (Cummins, 1988; Luster and Faith, 1979).

Floating plastic debris is very common in the marine environment, and there is increasing concern about its impact on marine life (Laist, 1987; Wolfe, 1987). This problem is particularly acute in the Mediterranean, where peculiar oceanographic conditions can favour the accumulation of floating plastic (Morris, 1980). Plastic ingestion is a known cause of cetacean mortality (Tarpley and Maritz, 1993), and the occurrence of plastic debris obstructing the digestive tract of stranded cetaceans is not uncommon in the Mediterranean (Cagnolaro and Notarbartolo di Sciara, 1992).

Acoustic Pollution

Human beings are making increasing use of the sea in their commercial, industrial and recreational activities and one consequence of this is the introduction of many new sources of sound to the marine environment. In some cases, such as shipping and offshore drilling, the production of sound is simply an unintentional, often unconsidered, byproduct of another activity. However, other underwater sounds, often very intense ones, are made deliberately. Examples include: various types of sonar, seismic surveys and oceanographic tomography. Because low frequency sound propagates so well underwater these noises may be detectable for tens or even hundreds of miles. Such unwanted noise is often termed 'acoustic pollution'. Sound is known to be a significant source of disturbance for humans and other land animals. Cetaceans, which are known to be highly acoustically oriented animals, relying on sound to communicate, to navigate, to find their food and for echolocation, may be particularly vulnerable.

The effects that various manmade noises in the ocean could be having on marine life have become a cause of increasing concern over the past few decades (see for example, Payne and Webb, 1971; Reeves, 1977; Myrberg 1978; Acoustical Society of America, 1981; Richardson and Würsig, this volume). The effects of intense sounds on cetaceans can range from acute physical damage, usually as a result of shock waves from explosions (Ketten *et al.*, 1993) through temporary or permanent deafness to a variety of behavioural effects. More general increased levels of background noise underwater could also affect cetaceans. For example, this could interfere with their ability to detect biologically important sounds by masking, disrupt their behaviour and impair their hearing sensitivity. Generally, cetaceans will be most vulnerable to sound at the frequencies to which they are most sensitive. Data on auditory sensitivity of cetaceans is rather sparse except for a few species which can be readily kept in captivity, and the auditory sensitivity of the great whales has been identified as a particularly important data gap (National Research Council, 1994). The smaller odontocete cetaceans are typically most sensitive at higher frequencies (>1 kHz) while the baleen whale's hearing system appears to be designed to maximise its sensitivity to low frequency sounds (Ketten, 1992), and by and large the vocalisations made by these two groups mirror these differences in hearing sensitivity. Thus we might expect the smaller odontocetes to be most vulnerable to adverse effects from high frequency sounds and the baleen whales to be most susceptible to low frequency sounds.

One of the most substantial sources of man made noise in the marine environment is shipping. Indeed, it has been estimated that shipping raised the overall level of background noise by 10dB between 1950 and 1975 and that the likely continuing increase in maritime traffic will result in a rise of another 5dB by the end of the 20th Century. The Mediterranean has some of the busiest shipping lanes in the world, and in the summer months at least, very large numbers of recreational power craft are also active there. In addition it has its share of offshore exploration and exploitation while its strategic importance ensures that there is substantial acoustic input from military sources.

Habitat Degradation

The Mediterranean Sea is bordered by some of the world's most heavily inhabited areas. It has a coastal human population of about 130 million, which is augmented by a seasonal influx of more than 100 million tourists every year (Anon., 1989). Human influence is particularly evident in the coastal zone, where waste loads from domestic sewage, industrial discharges, oil spills and agricultural run-off have deeply modified the marine environment in many areas. In addition to the direct effects of pollution on cetaceans, the loss of biodiversity resulting from human activities is causing the depletion of food resources for coastal dolphins, which in turn aggravates competition with fisheries. Furthermore, intense ship traffic due to cargo vessels, oil tankers, ferries, hydrofoils, military, fishing and recreational vessels is generating in many areas high levels of disturbance, and creates the risk of collisions. Reports of cetaceans such as fin whales, sperm whales, pilot whales, and common and striped dolphins being rammed by vessels in the Mediterranean are common (Cagnolaro and Notarbartolo di Sciara, 1992).

SIGNS OF CHANGE

Quantitative historical data on Mediterranean cetacean populations do not exist and this means that it is not possible to show numerical or distributional trends in any Mediterranean cetacean population. However, there are several examples of dramatic changes in cetacean populations in the Mediterranean. In spite of the absence of detailed quantitative data, these can at least be used to focus future research effort. Pending a full description and understanding of the phenomena, it would be prudent to be guided by the precautionary principle, and to assume that such changes are at least partially caused by human activities.

Common dolphins are a cosmopolitan species, found both in coastal and pelagic waters. The common dolphin was once abundant throughout the Mediterranean, and until recent times was considered one of the commonest cetaceans in the region (Duguy and Cyrus, 1973; Casinos and

Vericad, 1976; Cagnolaro *et al.*, 1983). Since the 70's, however, declines in common dolphin strandings and sightings have been noted in both the western Mediterranean and in the Adriatic Sea (Casinos and Filella, 1977; Duguy *et al.*, 1983b; Viale, 1985; Notarbartolo di Sciara *et al.* 1993). The reason(s) for such decline are still a matter for conjecture. Viale (1985) suggests competitive exclusion by *Stenella coeruleoalba*; however, this would not explain the disappearance of common dolphins from the Northern Adriatic Sea. Here common dolphins were once abundant (Brusina, 1889), living sympatrically with bottlenose dolphins and although common dolphins have disappeared they have not been replaced by striped dolphins. Today, common dolphins in the Mediterranean are known to co-exist with striped dolphins in the Alboran Sea (Forcada, in press), and with bottlenose dolphins in the coastal waters of Ionian Greece (Politi *et al.*, 1992). It has been argued that common dolphins may have been rare in the Mediterranean for a long time but that this remained unnoticed due to the frequent mis-identification of striped dolphins as commons (Collet, 1994). However, there is a wealth of reliable old observations and cetacean specimens acquired by scientific collections earlier in the Century that contain many more examples of *D. delphis* than *S. coeruleoalba* (Viale, 1985; Cagnolaro and Notarbartolo di Sciara, 1992). The decline of common dolphins in the Mediterranean remains unexplained, in part, because of the lack of past information on this species' population ecology. A deterioration in environmental conditions, which may have tilted the balance in favour of other, better adapted species occupying similar niches, is one reasonable hypothesis, but is difficult to test.

Between 1990 and 1992 a massive die-off of striped dolphins occurred in the Mediterranean Sea, spreading eastward from the Catalonian coasts to the Aegean Sea. This was due to an outbreak of a morbillivirus infection (Aguilar and Raga, 1993). Extremely high concentrations of PCBs were detected in dolphins effected by the epizootic, including the highest levels of the highly toxic non-ortho coplanar PCBs reported to date (Kannan *et al.*, 1993). In this instance it was thought that high PCB concentrations may have depressed the immune system of striped dolphins, ultimately leading to the morbillivirus outbreak (Kannan *et al.*, 1993).

The sperm whale is considered in the past to have been a reasonably abundant cetacean in the Mediterranean. However, recently it has been rather rarely encountered, during either visual (Notarbartolo di Sciara *et al.*, 1993) or acoustic (Borsani *et al.*, 1993) surveys. Although quantitative data from the past are lacking, old accounts, *e.g.* from the Strait of Messina, describe the frequent and conspicuous winter occurrence of large

(15–30 indiv.) sperm whale herds (Bolognari, 1950, 1951); such events are unheard of today. In three such occurrences in November and December 1947 a number of whales, including calves, were killed with TNT charges by the local fishermen for no apparent reason (Bolognari, 1949). Bayed and Beauburn (1987) report a decrease of sperm whale occurrence in the Gibraltar area. The hypothesis that sperm whale numbers in the Mediterranean are declining in response to human impact (Duguy *et al.*, 1983a, 1983b), including bycatch in pelagic driftnets (Cagnolaro and Notarbartolo di Sciara, 1992; Anon., 1994) and interference from vessel traffic (Duguy *et al.*, 1983a) needs to be investigated further.

The bottlenose dolphin, *T. truncatus*, is the most widespread coastal mammal of the region, occurring along the continental shelf from Gibraltar to the eastern shore of the Black Sea (Di Natale, 1987; Hussenot and Robineau, 1994). However, it is clear that wide gaps in the distribution of the species are developing. In areas in which bottlenose dolphins were once considered frequent, such as along the western shore of the Adriatic Sea, they are now rare (Notarbartolo di Sciara and Bearzi, 1992). Greenwood and Taylor (1978) report a heavy parasitic load and a general state of bad health for bottlenose dolphins captured in the Adriatic for the aquarium industry. The status of bottlenose dolphins in the Mediterranean needs to be properly documented, and with some urgency, to provide the basis for quantifying their possible decline or for judging its causes (Reeves and Leatherwood, 1994).

ACOUSTIC METHODS

It is clear that many of the problems facing Mediterranean cetaceans are acute and that if solutions are not found speedily, long term impoverishment of the region's cetacean fauna could result. Often a lack of very basic information is hindering the search for these solutions and conservation biologists will need to use all the tools and techniques at their disposal if they are to provide this information speedily. It is also likely that they will have to achieve this on rather meagre budgets. We propose that in some cases field techniques that utilise passive acoustics will be among the most useful and cost-effective methods to employ.

Acoustic Surveys

All whales and dolphins are difficult to spot and identify at sea, even in the best of conditions, and when the weather deteriorates, sighting some species of cetacean borders on the impossible. On the other hand, many cetaceans make loud characteristics vocalisations and sound propagates very well through the sea. Such observations suggest that passive acoustic techniques will often be very effective, complementing or even replacing traditional visual methods.

For some species at least, acoustic surveying techniques offer a number of advantages when compared to visual methods:

1. The acoustic range of vocalisations is more predictable than visual range. Underwater acoustics is a sophisticated and well-developed branch of science, thanks largely to the intense interest that the world's Navies have had in this area. The range at which a given sound can be heard varies with its frequency and with certain oceanographic conditions which affect propagation, but given a knowledge of these conditions maximum detection range can be estimated. In addition, it is often possible to calculate range directly, by using arrays of hydrophones (*e.g.* Watkins, 1976). By contrast there is no theoretical understanding of the complex factors that affect a human observer's ability to detect cetaceans visually and this often varies with subtle changes in physical conditions, sometimes in unexpected ways.
2. Acoustic range is less effected by meteorological conditions than visual range. Visual range at which cetaceans can be spotted is curtailed rapidly with increasing sea state and surveys are rarely continued at sea states about Beaufort three. Although the level of background noise increases with sea state and this masking noise reduces detectability in acoustic surveys, the effect is measurable and resultant range reductions are predictable. In practice acoustic surveys can usually continue in higher sea states than visual surveys.
3. Often (particularly when small research vessels are used) acoustic range is superior to visual range. The range at which cetaceans can be seen or heard varies from species to species but many can be detected acoustically at a greater range than they can be seen. It is rare, without specialist platforms and equipment, to be able to see, let alone reliably identify, a whale at ranges over 2 km. However, using simple monitoring equipment in low sea states, we have measured acoustic ranges of 2 km for dolphins in the Mediterranean. Sperm whales can be reliably heard at ranges of 5–9 km using simple hydrophones while Sparks *et al.* (1993) report detecting sperm whales at ranges of 18 km using a towed linear array. Some of the large baleen whales can be heard with surface hydrophones at tens of km range.

4. Acoustic surveys are less onerous than visual surveys. Searching for whales is hard work and requires constant vigilance from experienced observers. Spotters have to be changed regularly and rested, and consequently large (expensive) field teams are required.
5. Acoustic surveys can be conducted 24 hours a day, both day and night. Obviously visual sightings are impossible in poor light conditions and at night. Most cetaceans continue to vocalise round the clock; however, allowances may have to be made for diurnal variation in acoustic output.
6. A complete permanent record can be made of acoustic survey cues. A high quality tape recording provides a remarkably complete record of the acoustic information within its band of sensitivity and this is then available for later analysis. The recent development of compact affordable digital tape records makes this particularly easy for sounds within their bandwidth (usually 10 Hz to 22 kHz). Visual data cannot be stored in this way.
7. There is a great potential for automation of data collection and detection. Modern digital processing techniques mean that many aspects of acoustic analysis, such as distinguishing, classifying, counting and timing vocalisations, can be performed automatically (Leaper *et al.*, 1992; Fristrup *et al.*, 1992; Stafford *et al.*, 1994). There are two main advantages of this. In the first place it further reduces the amount of human effort that needs to be expended. Secondly, and most importantly, it removes sources of human error due to inter-individual variability in the ability to make detections.
8. Generally, acoustic surveys are well suited for completion from small research boats or platforms of opportunity. Visual surveys generally require large vessels to provide steady elevated viewing platforms and to accommodate large teams of spotters. Often, acoustic surveys can be conducted from very modest vessels, in fact because smaller displacement boats are generally quieter they may even be preferred. Small vessels are much cheaper to charter and run than large ones, so more surveying effort can be achieved for an equivalent expenditure.

Acoustic surveys of different degrees of sophistication require different types of data and will provide different levels of information.

Simple Qualitative Surveys

At the most basic level acoustic methods could play an important role in establishing the range and distribution of species. The cetacean populations in some parts of the Mediterranean, especially the eastern and southern regions, are poorly known while information from other areas is still very much biased towards the summer months. Useful data could be collected by using simple hydrophones to make recordings in these areas to establish which species were present. In many cases such recordings could be made by untrained volunteers, such as yachtsmen. This sort of survey might be thought of as an acoustic equivalent of the opportunistic visual sighting schemes which have been run in many parts of the world.

This approach, and more sophisticated ones, rely on an ability to identify species from their vocalisations. This emphasises the importance of establishing comprehensive databases of underwater sounds (*e.g.* Ranft, this volume; Pavan and Borsani, this volume). One striking area of ignorance at this time is the winter distribution of fin whales in the Mediterranean and the location of their breeding grounds. It has recently been shown, using genetic techniques, that the Mediterranean population of fin whales is distinct from other fin whale populations in the Atlantic (Berubé *et al.*, 1994). It is known that in the summer months fin whales are abundant in the Liguro-Provençal-Corsican basin, indeed most of the Mediterranean population is believed to concentrate there. (Some of this region has now been declared a Sanctuary so at least part of their feeding grounds are protected). Fin whales are less common in this area in the spring/winter when they should be breeding, but the location of their breeding grounds is not known. A first step to achieving protection for fin whales during this vulnerable period of their lives must be to locate these breeding areas.

The problem then is to search a very large area of the sea, at an inclement time of the year, on a small budget. Fin whales make very loud low frequency vocalisations. Their calls, with dominant frequencies around 20 Hz and source levels as high as 186 dB re 1 Pa at 1 m, are detectable at ranges of tens of kilometres using surface hydrophones (Watkins, 1981) and over hundreds of kilometres using bottom mounted military hydrophone arrays (Mellinger, this volume). Data from suitable military hydrophone systems are not available in the Mediterranean. One obvious strategy for determining fin whale distribution in winter would thus be to conduct acoustic surveys monitoring low frequency hydrophones or sonobuoys. Once concentrations of wintering fin whales are located, other methods, such as photo-identification and biopsy sampling, could be utilised to gain more detailed information on the population.

Acoustic Methods Used in Support of Visual Surveys

Thomas *et al.* (1986) used a towed hydrophone array to detect and classify cetaceans in conjunction with visual sightings surveys. They reported that it significantly enhanced detection of cetaceans, especially in high seas. They advocated using such arrays in conjunction with sightings surveys to provide more accurate estimates of distribution and abundance.

A major, ongoing, survey in the Gulf of Mexico is also using acoustic monitoring in conjunction with visual surveys to determine the distribution of cetaceans and relate these to oceanographic conditions (Davis *et al.* 1993). The towed linear array being deployed is mainly useful for detecting odontocetes with sperm whales being detected at ranges of 18 km (Sparks *et al.*, 1993).

Standardised Monitoring

Systematic acoustic monitoring using standard equipment can be used to obtain an index of abundance of vocalising animals. This could be used to show their distributions, to locate important habitats and to reveal temporal changes in abundance. The International Fund for Animal Welfare (IFAW) and Tethys Research Institute (Tethys) have been collaborating to establish such a scheme to monitor odontocete populations within the Ligurian Sea Cetacean Sanctuary.

Duplicate equipment, consisting of custom-built towed stereo hydrophones and Sony TCD10pro DAT recorders, were deployed from three vessels working within the Ligurian Sea Sanctuary. These boats did not keep to predetermined tracks while collecting survey data but their movements were independent of knowledge of cetacean distributions. Every 15 min the engine was put into neutral and if necessary the boat was slowed, so that a 1 min recording could be made. Researchers also monitored the hydrophones and scored the levels of dolphin and pilot whale whistles and clicks, and of sperm whale clicks, as well as levels of background water noise, shipping noise and self noise. These data were recorded directly into a computer.

These simple data provide information on dolphin distribution. Figure 1 for example summarises the results of 3587 monitoring sessions made from two vessels working within the Ligurian Sea Sanctuary between June and September 1994. It shows that dolphins (which in this area will virtually all be *S. coeruleoalba*) are widely distributed in offshore waters but less common close to the coasts. Such information assists in optimising the design of dedicated visual surveys. In addition, providing that standard equipment

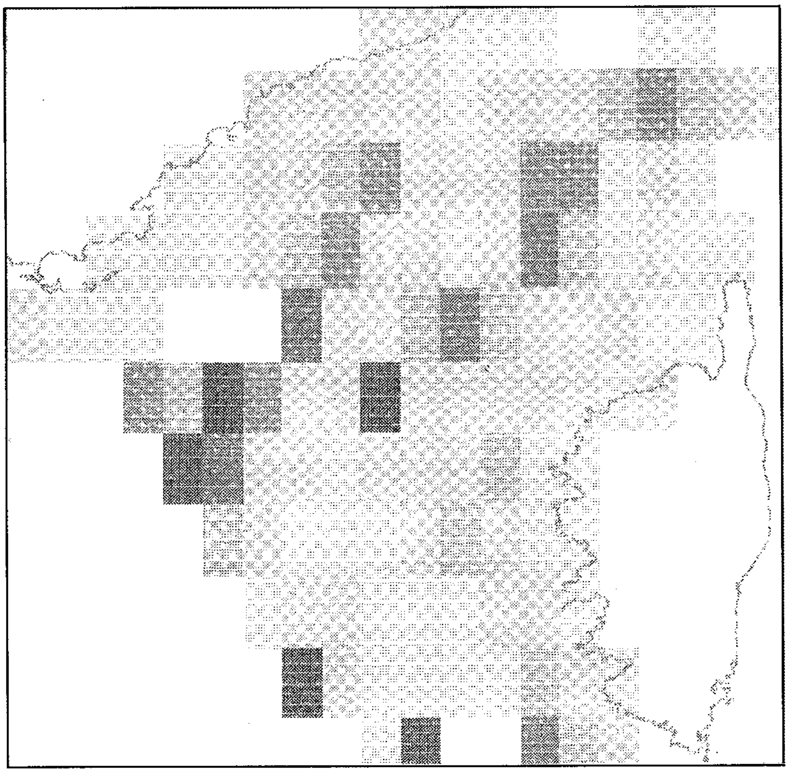

FIGURE 1 Distribution of dolphins in the Ligurian Sea revealed by standardised passive acoustic monitoring. Shading in each 15 × 15 nautical mile cell indicates the proportion of monitoring in which dolphin clicks could be heard clearly.

continues to be used, data suitable for deriving a reliable index of abundance, capable of showing changes in population densities between years, can be collected.

We are currently investigating whether it will be possible to make the method more quantitative by measuring the intensity of whistle vocalisations recorded at each station. These vocalisations are not very directional, so the average intensity of whistles should provide a fairly approximate indicator of range to vocalising animals. If this is the case, then data will be generated which could be analysed by point transect type methods.

Quantitative Acoustic Surveys

Acoustic methods have been used to count animals directly or to derive actual density estimates on relatively few occasions so far. Off Point

Barrow, Alaska, sonobuoys were deployed through fast-ice to create a long baseline array used to locate and track vocalising bowhead whales, *Balaena mysticetus*, as they migrated past the point (Clark *et al.*, 1985; Clark and Ellison, 1989; Zeh *et al.*, 1988). These tracks were used to determine minimum numbers of migrating whales.

A simple method for assessing sperm whale populations was developed in the Azores by Leaper *et al.* (1992). Digital signal processing techniques were used to determine bearings to vocalising whales by timing the arrival of clicks at a small array of three hydrophones deployed from a modest motor sailing vessel. These data were then used to determine effective acoustic range and population densities using the 'Cartwheels' approach (developed by Hiby and Lovell; Conservation Research Group, 1989). This simple technique would be suitable for conducting quantitative surveys of sperm whale populations within the Mediterranean, where these whales seem to be under threat. The scope for conducting quantitative acoustic surveys of other species should increase in the future as new acoustic methods are developed.

In addition, it is worth noting that body length may be estimated by analysis of the vocalisations of sperm whales (Norris and Harvey, 1972; Gordon, 1991). Thus, for this species, the size distribution of populations as well as densities, can be determined acoustically.

ASSESSING OTHER FACTORS OF CONSERVATION IMPORTANCE

Stock Divisions

Some populations of cetaceans have been shown to have distinctive vocalisations which reflect breeding or social divisions. For example, killer whales in different social groups have distinct dialects (Ford and Fisher 1982, 1983) and humpback whales on different breeding grounds sing quite distinct songs (Payne and McVay, 1971). The situation in sperm whales is more complex. This species can produce distinct patterns of clicks ('codas') and the most frequently produced codas (common use codas) seem to be different in different areas. Intriguingly, only one very distinctive coda has ever been recorded in the Mediterranean (Borsani *et al.*, 1992; Pavan and Borsani, this volume). This in itself may indicate a fairly homogenous population and it suggests that acoustic methods could be of value in exploring the possibility of links with sperm whale populations in the N.E. Atlantic.

Fin whale populations which are geographically isolated also seem to produce somewhat different calls. Recordings of Mediterranean fin whales might thus provide insights into the degree of their isolation from N.E. Atlantic stocks.

Behaviour

Vocalisations are an important aspect of cetacean behaviour in their own right and should be considered as part of any behavioural assessment. In addition, for the reasons mentioned in the previous section, at sea it will often be more practical to measure behaviour acoustically than visually.

Behavioural monitoring is important for assessing the welfare of cetaceans and for determining the effects on them of various sources of disturbance including pollution. A knowledge of such fundamental features as diurnal or seasonal patterns in behaviour is important for many aspects of management, as well as for planning and understanding acoustic and visual population assessments.

At present our ability to appreciate the significance of changes in vocal behaviour is limited by our rather sparse understanding of the meaning of different vocalisations (the same can also be said of many visual cues). However, the function of some vocalisations is clear. Odontocete clicks, for example, are mainly used for echolocation, and the marked diurnal variation in click production shown by the IFAW/Tethys acoustic monitoring data from the Ligurian Sea (Figure 2) very probably indicates that striped dolphins feed mainly at night.

Disturbance of cetaceans will usually be mediated acoustically, *i.e.*, cetaceans will most probably hear rather than see a source of disruption. Consequently, acoustic considerations should play a major part in studies of disturbance. Monitoring vocal behaviour will often be a useful way of measuring disturbance, especially as it provides some indication of an animal's activities when it is away from the surface. It should be remembered that it is when they are underwater that these animals perform many of their most significant behaviours. An acoustic approach to investigating disturbance of sperm whales by whale watching vessels was successfully employed by Gordon *et al.* (1992).

Fisheries Interactions

Acoustic considerations have rightly played an important part in investigations of the problems of cetacean bycatch in fishing nets, which is a major

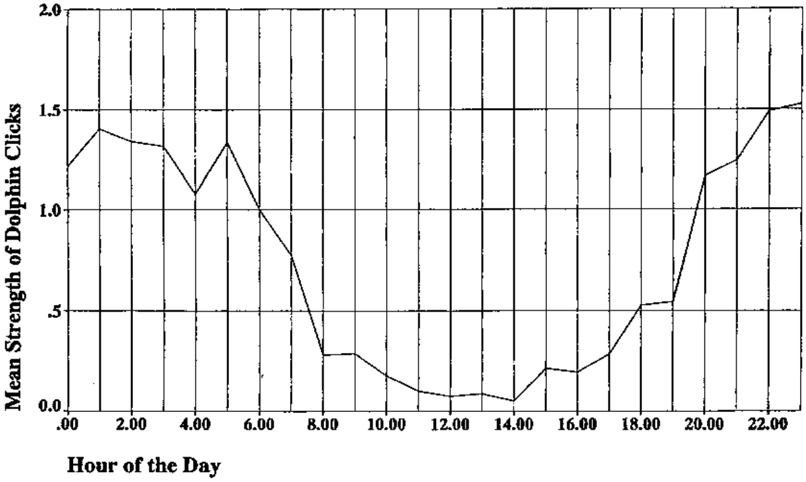

FIGURE 2 Diurnal variation in dolphin vocalisation rates in the Ligurian Sea revealed by standardised passive acoustic monitoring. 'Strength of dolphin clicks' during each standard 1 min monitoring session was assigned a score between 0 and 5 by fieldworkers.

problem in the Mediterranean (see for example Goodson, this volume). This is partly because entanglement may result from a cetacean's failure to detect a net acoustically using echolocation and this may be alleviated by making nets better sonar targets. It may also be the case that acoustic warning devices can be used to alert cetaceans to the nets' presence or to scare them away. One critical area of ignorance concerns the normal activities and echolocatory behaviour of cetaceans in areas where nets are set and their typical behaviour on encountering real nets in the open sea. Useful information relating to this could be obtained using simple passive acoustic monitoring techniques.

Acknowledgments

We wish to thank Patrizia Torricelli, Michael L. Fine, Gianni Pavan, and Marco Lugli, organisers of the Underwater Bioacoustics workshop, and Danilo Mainardi, director of the Erice School of Ethology, for inviting us to participate to a most stimulating event. The paper has benefited from the comments made by two reviewers, Bernd Würsig and David Goodson. Field research mentioned in this paper was supported by Tethys and the International Fund for Animal Welfare, and partly by the 'Centro Interdisciplinare di Bioacustica', University of Pavia. Jonathan Gordon works as a consultant to IFAW.

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