CETACEANS IN LIVERPOOL BAY AND NORTHERN IRISH SEA

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INTRODUCTION Liverpool Bay and the waters adjacent to the northern Irish Sea are not rich areas for cetaceans compared with other parts of the United Kingdom. Fifteen species of cetaceans have been recorded since 1975 in nearshore waters (within 60 km of the coast) (Evans, 1996b, Sea Watch, unpublished data). These include six species which are either present at any time of the year or recorded annually as seasonal visitors: minke whale *Balaenoptera acutorostrata*, long-finned pilot whale *Globicephala melas*, Risso's dolphin *Grampus griseus*, bottlenose dolphin *Tursiops truncatus*, common dolphin *Delphinus delphis*, and harbour porpoise *Phocoena phocoena*. Other cetacean species that have been recorded only casually in the region include: fin whale *Balaenoptera physalus*, sei whale *Balaenoptera borealis*, sperm whale *Physeter macrocephalus*, northern bottlenose whale *Hyperoodon ampullatus*, Sowerby's beaked whale *Mesoplodon bidens*, white-beaked dolphin *Lagenorhynchus albirostris*, Atlantic white-sided dolphin *Lagenorhynchus acutus*, striped dolphin *Stenella coeruleoalba*, and killer whale *Orcinus orca*.

STATUS & ECOLOGY The status, seasonal occurrence, and ecology of the six species of cetaceans recorded regularly in recent years in the region under review are given below:

Minke Whale (*Balaenoptera acutorostrata*) Worldwide distribution in tropical, temperate and polar seas of both hemispheres. In the North Atlantic, the minke whale occurs from Baffin Bay in the west and the Greenland & Barents Seas in the east, south to the Lesser Antilles in the west and the Iberian Peninsula and Mediterranean in the east. The minke whale is widely distributed along the Atlantic seaboard of Britain and Ireland although it also occurs regularly in the northern and central North Sea as far south as the Yorkshire coast. It is seen in small numbers in the Irish Sea but is rare in the Channel and southernmost North Sea, as well as south of here in the Bay of Biscay. There is some indication of an increase since the 1980's, with populations concentrated in the northern North Sea, and around North and West Scotland. No population estimates exist for this species for this region.

Most sightings occur in July-August although the species can be seen anytime between May and October, and at least small numbers remain in coastal waters year-round (Evans, 1980, 1992; Evans *et al.*, 1986; Northridge *et al*., 1995). In the autumn there appears to be a general offshore movement, possibly associated with breeding which occurs sometime between autumn and spring; however, breeding locations are unknown. There is no information on whether any more extensive migration takes place.

Most sightings occur in a band of the northern Irish Sea in offshore waters between the Isle of Man and Anglesey (between 53 and 54^{o} N, and between 4 and 6^{o} W). There is another cluster of sightings off south-west Scotland in the vicinity of the Mull of Kintyre and the islands of Arran and Jura. No live sightings of the species have been reported from Liverpool Bay itself, although the species has been reported offshore south-east of the Isle of Man.

The species is most commonly seen singly or, less commonly, in loose groups of up to three; in late summer in northern Britain loose feeding aggregations may form, but in the northern Irish Sea the species appears to be too rare for this to occur.

Minke whales feed upon a variety of fish species, notably herring, sandeel, cod, haddock, and saithe, as well as on invertebrates like euphausiids and pteropods. Feeding occurs often in areas of upwelling or strong currents around headlands and small islands, primarily during the summer. Feeding minke whales in late summer are commonly associated with flocks of manx shearwater, northern gannet, kittiwake and various *Larus* gulls.

Vocalisations involve intense, low frequency, broadband (0.5-1 kHz bandwidth) and harmonic down-sweeps with maximum source level of 165 dB re 1 μPa. These include short broadband downsweeps (mainly 0.13-0.06 kHz lasting 200-300 msecs); 'grunts' (mainly between 0.08-0.14 kHz, but up to 2 kHz, lasting 165-320 msecs); and thumps (often downsweeps; mainly 0.1-0.2 kHz, lasting 50-70 msecs) (Schevill & Watkins, 1972; Winn & Perkins, 1976; Thompson *et al*., 1979; Edds, 1988).

International protection includes Appendix II of CMS Agreement on the Conservation of Migratory Species of Wild Animals (BONN Convention, 1983); Appendix III (can be exploited so long as regulation keeps populations out of danger) of BERN Convention on the Conservation of European Wildlife and Natural Habitats (1982); and Annex IV Animal and Plant Species of Community Interest in Need of Strict Protection of the EU Habitats Directive (1992). It is listed on List C1 of Council Regulation and is treated by the European Community as if it is on CITES Appendix I (trade strictly controlled, and not for primarily commercial purposes, with exception of West Greenland); one of the species managed by the International Whaling Commission. Status listed by IUCN (in full initially) (1991) as vulnerable. In UK, it receives protection under The Wildlife & Countryside Act (1981) and the Wildlife (Northern Ireland) Order (1985).

Long-finned pilot whale (*Globicephala melas*) Worldwide distribution in temperate and sub-polar seas of both hemispheres (but absent from the North Pacific). The species is common and widely distributed in deep North Atlantic waters, but seasonally enters coastal areas such as the Faroes, northern Scotland, western Ireland and the south-west Channel Approaches; it also occurs south to the Iberian Peninsula and is common in the Mediterranean.

In the northern Irish Sea, the long-finned pilot whale is reported mainly from the vicinity of the Isle of Man where it occurs more or less annually in small numbers. The nearest sightings to Liverpool Bay are from Morecambe Bay and the east coast of Anglesey. Although recorded in most months of the year, peaks in sightings (and numbers of individuals) occur between April and August.

Sightings surveys in the eastern North Atlantic in the late 1980's (Buckland *et al.*, 1993) estimate the population at 778,000 (CV=0.295), but the difficulty of accurately estimating group size and distance of the centre of the group from survey vessels imposes serious limitations to the accuracy of such estimates whilst the area of coverage did not extend fully into UK waters. The species usually occurs in deep temperate and sub-polar waters (mainly 200-3,000m depth) seaward and along the edges of continental shelves where bottom relief is greatest, although it may venture on occasions into coastal waters entering fjords and bays.

Although there is no distinct breeding season, births in UK waters show a slight peak in late winter to early spring (January to March) (Evans, 1980; Martin *et al*., 1987). In the neighbouring Faroe Islands, births occur most frequently between July and September (Desportes *et al*., 1993; Martin & Rothery, 1993) although the differences may simply reflect inter-pod variation.

A highly social species, long-finned pilot whales are usually found in groups of 6-40 animals although pods in offshore deep waters can range to more than 1,000 individuals.

Cephalopods form the bulk of the prey in all dietary studies of this species, although a wide variety of fish have also been found (Sergeant, 1962; Desportes, 1985; Clarke, 1986; Waring *et al*., 1991; Desportes & Mouritson, 1993; Bernard & Reilly, 1999). Examination of the stomach contents of 857 pilot whales from the Faroes Islands revealed twelve genera of cephalopods, fifteen genera of fish, and three species of Crustacea (Desportes & Mouritson, 1993). The prey were mainly oceanic, mid-water pelagic shoaling species, and most of the squid were luminous. Two species of squid, *Todarodes sagittatus* and *Gonatus* sp., were the dominant prey, the former appearing to be the preferred food.

When unavailable, other prey items including fish (mainly greater argentine *Argentina silas* and blue whiting *Micromesistius poutassou*) and shrimps (mainly *Pandalus montagui*) were taken. Fish were more important in summer, especially in the diet of males (although squid continued to make up the bulk of the food), whilst in winter, prey species diversity increased. The diet varied with reproductive status (e.g. fish were of very low importance in non-lactating mature females) and between years (*Todarodes* was much more important in some years compared with others).

Seasonal onshore movements of pilot whales in different areas have been correlated with the abundance of prey: the squid *Illex illecebrosus* off Newfoundland (Mitchell, 1975), the squid *Todarodes sagittatus* off the Faroes (Desportes & Mouritson, 1993), the squid *Loligo paei* and mackerel *Scomber scombrus* off the north-eastern United States (Payne & Heinemann, 1993); whilst Evans (1980) reported seasonal movements (and by-catches) associated with mackerel fisheries in South-west England.

Vocalisations include tonal whistles in the range 0.5 – 5 kHz (mean of 4 kHz) with a mean duration of 0.73 secs (Taruski, 1979) and a maximum source level of 178 dB re 1µPa @ 1 m; and very variable click pulses (ranging up to thousands of clicks per sec) with energies from 0.2 to over 100 kHz (Busnel and Dziedzic, 1966; Watkins, *pers. comm.*) and maximum source levels of 180 dB re 1µPa @ 1 m. Significant correlations have been found between seven classes of whistle and particular behaviours. Simple whistles correlated with low activity and resting behaviours whilst complex whistles correlated with vigorous, energetic behaviour and high arousal states (Taruski, 1979; Weilgart and Whitehead, 1990).

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Risso's Dolphin (*Grampus griseus*) Worldwide distribution in tropical and temperate seas in both hemispheres. In the North Atlantic, it occurs from Newfoundland to the Lesser Antilles in the west; and from the Shetland Islands to the Mediterranean in the east. The species also occurs around oceanic islands like the Azores, Canaries and Cape Verde Islands.

The major populations in the UK occur in the Hebrides but the species is regular also in the Northern Isles, the Irish Sea, and off Western Ireland (Evans, 1992). It is rare or absent in the central and southern North Sea and eastern portion of the Channel. Elsewhere, it is present in Northwest France, the Bay of Biscay, around the Iberian Peninsula, and in the Mediterranean. In the northern Irish Sea, Risso's dolphins are seen mainly off the north Welsh coast (Lleyn Peninsula and Bardsey Island), and around the Isle of Man. It has not been recorded live from Liverpool Bay. The species is nowhere common but is seen most frequently between May and September, particularly the latter three months of July, August and September.

Risso's dolphins feed mainly upon cephalopods (octopus, cuttlefish and small squid), and the area is important both for feeding and breeding (calving occurring mainly between April and September). Stomach content analysis of stranded animals indicate that octopus and cuttlefish are amongst important prey. Groups usually comprise 5-20 individuals although sometimes in areas like north-west Scotland where the species is more common, aggregations of 50-100 individuals have been recorded.

Vocalisations include a variety of clicks, whistles, and pulsed calls. Whistles are rarely heard, but range over 2.5-20 kHz, usually 8-12 kHz, average duration 0.67 secs, and maximum source level of 170 dB re 1µPa @ 1 m (Watkins, *pers. comm*.). Clicks have peak frequency at 65 kHz and durations of 40-100 secs (Au, 1993). Click frequencies are between 0.2-over 100 kHz, with repetition rates of 4-200 per sec. Click-bursts last from 0.2-1.5 secs. Maximum source level is 175 dB re 1µPa @ 1 m (Watkins,

pers. comm.). Eight different kinds of sounds in three main categories were recognised in North-west Scottish Risso's dolphins: clicks in discrete series (echolocation clicks, creaks, grunts) with repetition rates of 37-167 pulses per sec., fast sequences of pulses (buzzes, squeaks, squeals, moans) with high repetition rates of 187-3,750 pulses per sec, resulting in harmonics; and whistles of 9-13.2 kHz (Benoldi *et al*., 1997, 1998).

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Bottlenose Dolphin (*Tursiops truncatus*) Worldwide distribution in tropical and temperate seas in both hemispheres. Along the Atlantic seaboard of Europe, the species is locally fairly common near-shore off the coasts of Spain, Portugal, north-west France, western Ireland, north-east Scotland, in the Irish Sea, particularly Cardigan Bay and south-east Ireland, and in the Channel. All those localities receive influence from the Gulf Stream. The species also occurs offshore in the North Atlantic (often in association with long-finned pilot whales) as far north as the Faroe Islands. In coastal waters, bottlenose dolphins often favour river estuaries, headlands or sandbanks where there is unneven bottom relief and/or strong tidal currents (Lewis & Evans, 1993; Liret *et al*., 1994; Wilson *et al*., 1997).

Essentially an inshore species, in British and Irish waters the bottlenose dolphin is most frequently sighted within 10 km of land, although it does also occur in offshore waters. Bottlenose dolphins are present throughout the year in various bays in Western Ireland; in the Irish Sea (particularly Cardigan Bay); and the Moray Firth. Elsewhere in Britain, the species has been scarce in the central and southern North Sea, but it occurs seasonally along the south coast of England at particular localities. In the Irish Sea, bottlenose dolphins are seen in greatest abundance in and around Cardigan Bay, west Wales, where a population of between one and three hundred occurs (Lewis, 1992; Arnold et al., 1997; Sea Watch, unpublished data). Although also reported widely from the northern Irish Sea, the species is uncommon there, with clusters of sightings occurring along the north coast of Anglesey, the south and south-west coasts of the Isle of Man, and in Morecambe Bay. Bottlenose dolphins have been seen in all months of the year though most frequently in April and between July and September, with groups usually varying between two and ten individuals including young. Elsewhere in the UK, group sizes tend to increase in late summer and may number tens of individuals.

The species has an extended breeding season, but with births peaking between May and November (Evans 1980; Wilson, 1995). Bottlenose dolphins feed upon a variety of benthic (e.g. eels, flounder, dab, sole, turbot, haddock, hake, and cod) and mid-water fish (e.g. salmon, trout, bass, mullet, herring, blue whiting) as well as marine invertebrates (cephalopods and shellfish).

The bottlenose dolphin makes a wide range of vocalisations. Echolocation clicks (used for orientation and foraging) are composed of intense short duration broadband clicks (40-130 kHz) (Au, 1993). Clicks are broadcast in episodic trains that can continue for the duration of a dive and culminate in buzzes and whines as targets are approached. Burst pulse vocalisations (barks, yelps and donkey-like brays) may have a variety of social functions (0.2-16 kHz). Whistles are pure tone frequency modulated calls ranging from 2-20 kHz. Clicks and whistle vocalisations can be made simultaneously.

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cetacean species, it is also listed on Annex IV Animal and Plant Species of Community Interest in Need of Strict Protection of the EU Habitats Directive (1992). It is listed on List C1 of Council Regulation and, since 1985, has been treated by the European Community as if it is on CITES Appendix II (trade controlled to prevent overexploitation). Status listed by IUCN (1991) as insufficiently known. In the UK, it receives special protection in respect of particular methods of killing or taking under The Wildlife & Countryside Act (1981) and the Wildlife (Northern Ireland) Order (1985). One of the species for which the Agreement on the Conservation of Small Cetaceans in the Baltic and North Seas (ASCOBANS) (1992), applies.

Common Dolphin (*Delphinus delphis*) Worldwide distribution in tropical, subtropical and temperate seas in both hemispheres. The common dolphin is widely distributed in the eastern North Atlantic, mainly in deeper waters from the Iberian Peninsula north to west Scotland. In British and Irish coastal waters, its distribution has a mainly western and southern component. It is common off the west coast of Ireland, in the western approaches to the Channel and the southern Irish Sea, also occurring regularly in summer around the Inner Hebrides north to the Isle of Skye (Evans, 1992; Northridge *et al*., 1995). In some years, the species occurs further north and east, around Shetland and Orkney, and in the northern North Sea. It is generally rare in the southern North Sea and the eastern portion of the English Channel. In recent years, there have been a number of sightings of common dolphins off Northern Scotland, in the Northern Isles, and well into the North Sea.

In the northern Irish Sea, common dolphins have been recorded over a wide area with no particular locality apparently favoured. The nearest sightings to Liverpool Bay are along the north Welsh coast. Most sightings in the northern Irish Sea occur between June and September, with group sizes numbering usually between one and twenty animals, occasionally up to fifty individuals.

The diet of the common dolphin includes a wide variety of fish and squid. Pelagic fish species are most common - blue whiting, mackerel, poor cod, hake, sardine, anchovy, silvery pout, scad, hake, and whiting, as well as small squid, octopus, cuttlefish, and crustaceans. Calves in UK waters are usually born between June and September.

Vocalisations vary from whistles of 1-50 kHz frequency (mainly 6-12 kHz, max. source level 172 dB) to echolocation clicks which have not been adequately described but may reach 150 kHz (max. source levels 170 dB) at repetition rates of 30-200 clicks/sec. and pulsed calls such as “buzzes” and “barks” (Evans, 1973; Watkins, pers. comm.; Sturtivant *et al*., 1994; Moore & Ridgway, 1995). Clicks and whistles may be given simultaneously.

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Harbour Porpoise (*Phocoena phocoena*) Distribution restricted to temperate and sub-arctic seas of the northern hemisphere. In the eastern North Atlantic, the harbour porpoise is widely distributed on the continental shelf from the Barents Sea south to the coast of France and Spain, although in the last thirty years it has become scarce in the southernmost North Sea, English Channel, and Bay of Biscay. Nevertheless, it is the commonest cetacean recorded in British and Irish waters, though most abundant along the south and west coasts of Ireland, western and northern Scotland including the Hebrides and Northern Isles, in East Scotland and Northeast England, and in some coastal areas within the Irish Sea (mainly off south-west Wales). Only small numbers occur in the Channel whilst general declines were noted in coastal areas of the southern North Sea during the 1970's, extending to and including some more northern and Atlantic sites during the early 1980's, with some indication of a reversal in this trend in the late 1980's to the present (Evans, 1992; Sea Watch, unpublished data).

The harbour porpoise is the most common cetacean species recorded in the northern Irish Sea where it is widely distributed but with clusters of sightings around the Isle of Man, off the Mull of Galloway, and off the north coast of Anglesey and the Lleyn Peninsula in north Wales. Although some sightings records have not been submitted yet to the national sightings database, there are recent reports of the species being observed in the vicinity of Liverpool Bay, occurring in small numbers from Hilbre Island (Cheshire Wildlife Trust, *pers. comm.*.). The species is apparently resident throughout the year in the region, although peak numbers are recorded between July and September. The area is used both for feeding and breeding.

The main diet of porpoises is small fish (usually less than 40 cm length) such as young herring, sprats, sand-eels, whiting, saithe, and pollack, although particularly in winter months, prey such as dab, flounder, sole, and cod are taken. Breeding occurs mainly between May and August, with a peak in June, though some can be as early as March.

Harbour porpoises produce high-frequency sounds used for echolocation and communication, but do not make frequency-modulated whistles typical of many delphinids. The high frequency sounds are comprised entirely of click trains, produced in two narrow band frequency components, one weaker one of longer duration (c. 0.2 msec) at between 1-20 kHz (Schevill *et al.*, 1969; Goodson *et al*., 1995) and the other between 120-160 kHz (peaking around 125-130 kHz) of shorter duration (c. 0.02 msec) (Mohl & Andersen, 1973; Kamminga, 1990; Amundin, 1991; Goodson *et al.*, 1995). Repetition rates of pulses range between 0.5-1,000 clicks per sec (Amundin, 1991). Maximum source level is estimated at between 149 and 177 dB re 1µPa at 1 m (Akamatsu *et al*., 1992). The contexts in which these click trains are used are not well understood.

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EFFECTS OF ANTHROPOGENIC SOUND UPON CETACEANS

Sound characteristics produced by human activities Animals such as cetaceans which live entirely within an aquatic environment rely heavily on sound both to acquire information about their environment and for communication (Evans, 1987; Richardson *et al*., 1995). Additional sounds may therefore cause disruptions to the lives of cetaceans, distracting, annoying or even frightening them, as well as providing the potential for causing behavioural and physiological upset.

Since the industrial era, humans have developed a number of highly intense sources of sound (Ross, 1976; Urick, 1983, 1986). Indeed, Ross (1976) estimated that between 1950 and 1975, ambient noise had risen by 10 dB in areas where shipping noise dominates, and he predicted it would rise a further 5 dB by the end of the 20th century as shipping traffic increased. The more powerful the engine that a vessel possesses, the greater the amount of sound (at least at low frequencies) it will produce. Supertankers, in particular, produce sounds at low intensities, generally below 10 Hz, with intensities recorded of between 187 dB (at 50 Hz) and 232 dB (at 2 Hz) re 1 µPa (Cybulski, 1977; Leggat, *et al.*, 1981).

Besides propeller and engine sound generated by vessels during commercial, military and recreational activities, surface vessels and submarines employ active sonar which uses sonic or ultrasonic waves to locate submerged objects, at the same time introducing brief, high-intensity pulses into the marine environment that sometimes may be transmitted over great distances. Source levels of sound are c. 200-250 dB re 1 μPa at frequencies up to 200 kHz. High resolution sidescan sonar (generally below 14 kHz) is also used in geophysical seismic surveys particularly during oil and gas exploration, along with lower resolution explosive techniques (airguns, sleeve exploders, etc.) mainly at frequencies below 500 Hz (Richardson *et al.*, 1995; Evans & Nice, 1996).

Most of the sounds generated from maritime activities referred to above (with the exception of sonar) are produced at frequencies lower than 1 kHz. However, when a surface vessel travels at high speed, the propeller may cavitate and produce much higher frequency sound (between 2 and 20 kHz) (Evans *et al.*, 1992). Measurements of various small craft (up to 15 m length, 240 hp engine) indicated source levels ranging from 100-125 dB re μPa at 2 kHz and 60-105 dB re μPa at 20 kHz. Cavitation is also more likely to occur when the propeller is damaged.

Cetacean Sound Production and Hearing The auditory sensitivities of porpoises, dolphins and the smaller toothed whales are greatest at very high frequencies - between 10 and 150 kHz, with a hearing threshold of about 40 dB at those frequencies, increasing to around 100 dB at 1 kHz and 120 dB at 100 Hz, at least for those species for which data are available (Richardson *et al.*, 1995). Although there is no quantitative information on the auditory sensitivities of baleen whales (such as the minke whale), results of recent investigations suggest that greatest hearing sensitivities occur between 100 Hz and 5 kHz, on the assumption that whales will hear approximately over the same frequency range as the sounds they produce. Using this argument, we would expect minke whales to be most sensitive to frequencies of between 60-140 Hz.

The sounds produced by toothed whales and dolphins may conveniently be divided into: (1) pure tone whistles generally in the frequency range 500 Hz - 20 kHz, used mainly for communication; and (2) pulsed sounds or clicks varying from 500 Hz to 150 kHz, used mainly for echolocation. Source levels for both types of sound are estimated usually to be between 150 and 200 decibels, although pulsed sounds for non-echolocatory purposes may be produced at source levels of 115 dB, mainly in the frequency range below 20 kHz. Most of these measurements were made in captivity and it should be noted that animals can modify their sound production (particularly its intensity) in confined situations, and indeed do so also in open water.

The sounds produced by baleen whales may be classified into four types: (1) low-frequency moans, typically with frequencies of 12-500 Hz and of 0.4 to 36 seconds duration; (2) grunt-like thumps and knocks with most sound energy concentrated between 40 and 200 Hz; (3) chirps, cries and whistles at frequencies between 1 and 10 kHz; and (4) clicks or pulses at frequencies up to 20-30 kHz and lasting from 0.5 to 5 msec. Sound source levels range between 150 and 200 decibels, at frequencies of 500 Hz or less.

To summarise, most toothed whales, dolphins and porpoises can hear sounds over a wide range of frequencies from 75 Hz to 150 kHz, with greatest sensitivity around 20 kHz (although low frequency hearing has not been fully investigated), whereas the hearing of baleen whales probably ranges from frequencies of 10 Hz to 10 kHz, with greatest sensitivity usually below 1 kHz (this is based on sound production levels since no audiograms exist). Major differences in hearing between baleen and toothed whales are further supported by anatomical differences between the hearing organs of these two groups.

Sounds generated within the hearing range of cetacean species tend to elicit specific responses: the animal or animals move away from the sound source; they increase their dive times, remaining underwater for longer periods (possibly as a result of a rapid flee response); and social groups may bunch together (Richardson *et al.*, 1995; Evans, 1996a). Sometimes, a cetacean species can shift the sound frequency at which it is communicating, and thus avoid or at least reduce interference with human made sounds. Long-term effects upon survival and reproduction of cetaceans have scarcely ever been demonstrated. However, because of the extreme difficulty of distinguishing from other anthropogenic factors and natural environmental changes, it is almost impossible to say whether these occur. From various anatomical and behavioural studies undertaken, the evidence suggests that cetaceans will show in the range of their peak hearing sensitivity, physical ear damage at c. 220 dB re:

1 µPa, whilst baleen whales show behavioural avoidance at around 160-170 dB re: 1 µPa (Evans and Nice, 1996).

Potential effects of sea-based wind power upon cetaceans in Liverpool Bay Offshore windmills are a recent development, the first starting in 1990 close to the coast of south-east Sweden. Since then, there have been a number of projects starting in several other European countries including the United Kingdom. However, very little data have been obtained regarding measured levels of noise and vibration near operational offshore wind farms nor of observed effects upon the distribution and behaviour of marine animals including marine mammals. This review of potential impacts on cetaceans must therefore be viewed in this light, recognising that assessment of effects has to be speculative.

A series of acoustic measurements were made upon the Swedish offshore wind turbine and suggested that the turbine generated low frequency tones peaking around 16 Hz at a sound level of c. 20 dB above background noise (assumed to be c. 80 dB re: 1 µPa in a fairly calm sea) at a distance of 100 m from the turbine (Westerberg, 1994, 1999). This seemed to be the case irrespective of wind speed (i.e. noise from the turbine and ambient noise levels increased at the same rate with increasing wind speed) such that the relative intensity of the turbine noise remained constant. From this measurement, the wind turbine's source level (at a distance of 1 metre) was estimated at c. 115-120 dB re: 1 µPa. No information exists as yet for the cumulative sound source levels of a number of turbines arranged in formation as in a wind farm.

No cetacean species is known to be resident in Liverpool Bay. The species which is most likely to visit the area is the harbour porpoise, and then only seasonally in small numbers. The hearing sensitivity and range of vocalisations of the porpoise centre upon the ultrasonic range, in the region of 100-200 kHz which is well above the peak frequencies recorded for the wind turbines (although it should be noted that the hydrophones used for those measurements were sensitive only up to 100 Hz). No baleen whale species (that vocalise at frequencies below 100 Hz) live in the immediate vicinity of Liverpool Bay, and those other cetacean species occurring in the region are all odontocetes (toothed whales and dolphins) whose hearing sensitivity and range of vocalisations is generally between 75 Hz and 150 kHz. For these reasons, it is not anticipated that the proposed wind farm will have a significant negative effect upon the cetacean fauna of the northern Irish Sea.

However, there are several gaps in our knowledge which need to be addressed before sea-based wind power can be regarded as of little consequence to cetaceans. First, measurements need to be made using detection equipment spanning all frequencies between 10 Hz and 200 kHz, in case some higher frequency sound is also generated by those activities. Second, although the source levels of one particular wind turbine has been measured, this needs to be repeated for other designs, and in particular, the cumulative effects of sound created by numbers of turbines at particular densities should be examined, along with other possible side effects (such as changes in water temperature, turbulence, etc) that could make the locality a less favourable environment for important activities like feeding.

REFERENCES & FURTHER READING

Akamatsu, T., Hatakeyama, Y., Kojima, T., and Soeda, H. (1992) The rate with which a harbor porpoise uses echolocation at night. Pp. 299-316. In: *Marine mammal sensory systems* (Eds. J.A. Thomas *et al*.) Plenum Press, New York.

Amundin, M. (1991) *Sound production in odontocetes with emphasis on the harbour porpoise Phocoena phocoena.* Doctoral dissertation, University of Stockholm.

Arnold, H., Bartels, B., Wilson, B., and Thompson, P. (1997) *The bottlenose dolphins of Cardigan Bay: Selected biographies of individual bottlenose dolphins recorded in Cardigan Bay, Wales.* Report to Countryside Council for Wales. CCW Science Report No. 209.

Au, W.L. (1993) *Sonar of Dolphins.* Springer-Verlag, New York.

Benoldi, C., Gill, A., Evans, P.G.H., Manghi, M., Pavan, G., and Priano, M. (1999) Comparison between Risso's dolphin vocal repertoire in Scottish waters and in the Mediterranean Sea. Pp. 235-239. In: *European Research on Cetaceans - 11.* (Eds. P.G.H. Evans & E.C.M. Parsons). European Cetacean Society, Valencia, Spain. 436pp.

Benoldi, C., Evans, P.G.H., Pavan, G., Manghi, M., and Priano, M. (1997) Acoustic survey of Risso's Dolphins in Hebridean Waters, Scotland. Pp. 232-236. In: *European Research on Cetaceans - 11* (Eds P.G.H. Evans, E.C.M. Parsons & S.L. Clark). European Cetacean Society, Kiel, Germany. 314pp.

Bernard, H.J. and Reilly, S.B. (1999) Pilot whales *Globicephala* Lesson, 1828. Pp. 245-279. In: *Handbook of marine mammals. Volume 6. The second book of dolphins and porpoises* (Eds. S.H. Ridgway and R. Harrison). Academic Press, London.

Buckland, S.T., Bloch, D., Cattanach, K.L., Gunnlaugsson, T., Hoydal, K., Lens, S., and Sigurjónsson, J. (1993) Distribution and abundance of long-finned pilot whales in the North Atlantic, estimated from NASS-87 and NASS-89 data. *Rep. Int. Whal. Commn*, (special issue 14), 33-49.

Busnel, R.-G. and Dziedzic, A. (1966) Acoustic signals of the pilot whale *Globicephala melaena* and of the porpoises *Delphinus delphis* and *Phocoena phocoena*. Pp. 607-646. In: *Whales, dolphins, and porpoises*. (Ed. K.S. Norris). University of California Press, Berkeley. 789pp.

Clarke, M.R. (1986) Cephalopods in the diet of odontocetes. Pp. 281-322. In: *Research on Dolphins* (Eds. M.M. Bryden and R. Harrison). Clarendon Press, Oxford.

Cybulski, J. (1977) Probable origin of measured supertanker radiated noise spectra. Pp. 15C-1 to 15C-8. In: *Oceans '77 Conference Record*. Inst. Electrical and Electronic Engineering., New York, NY.

Desportes, G. (1985) *La nutrition des Odontocètes en Atlantique Nord-Est* (*côtes Françaises - Iles Feroë*). PhD Thesis, University of Poitiers. 190pp

Desportes, G. and Mouritsen, R (1993) Preliminary results on the diet of long-finned pilot whales off the Faroe Islands. *Rep. Int. Whal. Commn* (special issue 14), 305-324.

Desportes, G., Saboureau, M., and Lacroix, A. (1993) Reproductive maturity and seasonality of male long-finned pilot whales, off the Faroe Islands. *Rep. Int. Whal. Commn* (special issue 14), 233-262.

Edds, P.L. (1988) Characteristics of finback *Balaenoptera physalus* vocalizations in the St. Lawrence Estuary. *Bioacoustics*, 1, 131-149.

Evans, P.G.H. (1980) Cetaceans in British Waters. *Mammal Review*, 10, 1-52.

Evans, P.G.H. (1987) *The Natural History of Whales and Dolphins*. Christopher Helm, London. 360pp.

Evans, P.G.H. (1990) Whales, Dolphins and Porpoises. The Order Cetacea. Pp. 299-350. In: *Handbook of British Mammals*. (Eds. G.B. Corbet & S. Harris) Blackwell, Oxford. 588pp.

Evans, P.G.H. (1992) *Status Review of Cetaceans in British and Irish Waters.* UK Dept. of the Environment, London. 98pp.

Evans, P.G.H. (1996a) Human disturbance of cetaceans. Pp. 376-394. In: *The Exploitation of Mammals - principles and problems underlying their sustainable use.* (Eds. N. Dunstone & V. Taylor). Cambridge University Press. 415pp.

Evans, P.G.H. (1996b) Whales, dolphins and porpoises. Chapter 5.15. Pp. 153-156. In: *Coasts and Seas of the United Kingdom. Region 13. Northern Irish Sea: Colwyn Bay to Stranraer, including the Isle of Man.* (Eds. J.H. Barne, C.F. Robson, S.S. Kaznowska & J.P. Doody). Joint Nature Conservation Committee, Peterborough.

Evans, P.G.H. and Nice, H. (1996) *Review of the Effects of Underwater Sound generated by Seismic Surveys on Cetaceans.* Report to UKOOA. Sea Watch Foundation, Sussex. 50pp.

Evans, P.G.H., Canwell, P.J., and Lewis, E.J. (1992) An experimental study of the effects of pleasure craft noise upon bottle-nosed dolphins in Cardigan Bay, West Wales. Pp. 43-46. In: *European Research on Cetaceans - 6* (Ed. P.G.H. Evans). European Cetacean Society, Cambridge, England. 254pp.

Evans, P.G.H., Harding, S., Tyler, G., and Hall, S. (1986) *Analysis of Cetacean Sightings in the British Isles, 1958-1985.* Nature Conservancy Council, Peterborough. 71pp.

Evans, W.E. (1973) Echolocation by marine delphinids and one species of freshwater dolphin. *Journal of the Acoustical Society of America*, 54, 191-199.

Goodson, A.D., Kastelein, R.A., and Sturtivant, C.R. (1995) Source levels and echolocation signal characteristics of juvenile harbour porpoises *Phocoena phocoena*. Pp. 41-54. In: *Harbour porpoises, laboratory studies to reduce bycatches* (Eds. P.E. Nachtigall *et al*.). De Spil, Woerden, The Netherlands.

Kamminga, C. (1990) Echolocation signal types of odontocetes. Pp. 9-21. In: *Animal Sonar*. NATO Advanced Studies Institute. Vol. A156.

Ketten, D.R., Lien, J., and Todd, S. (1993) Blast injury in humpback whale ears: Evidence and implications. *Abstract* In *J. Acoust. Soc. Amer.,* 94(3): 1849-1850.

Leggat, L.J., Merklinger, H.M., and Kennedy, J.L. (1981) LNG carrier underwater noise study for Baffin Bay. Pp 115-155. In: *The Question of Sound from Ice-breaker Operation* (Ed. N.M. Peterson). The Proceedings of a Workshop, Arctic Pilot Project, Petro-Canada, Calgary, Alberta.

Lewis, E.J. (1992) *Social cohesion and residency of bottle-nosed dolphins (Tursiops truncatus) in west Wales. An analysis of photographic data.* BSc Thesis, University of Leeds. 31pp.

Lewis, E.J. and Evans, P.G.H. (1993) Comparative ecology of bottle-nosed dolphins (*Tursiops truncatus*) in Cardigan Bay and the Moray Firth. Pp. 57-62. In: *European Research on Cetaceans - 7.* (Ed. P.G.H. Evans). European Cetacean Society, Cambridge, England. 306pp.

Lien, J., Taylor, D.G., and Borggaard, D. (1995) Management of Underwater Explosions in Areas of High Whale Abundance. *Marienv 1995* . Proceedings of the International Conference on Technologies for Marine Environment Preservation. Vol. 2, 627-532.

Liret, C., Allali, P., Creton, P., Guinet, C., and Ridoux, V. (1994) Foraging activity pattern of bottlenose dolphins around Ile de Sein, France, and its relationships with environmental parameters. Pp. 188-191. In *European Research on Cetaceans - 8*. Editor P.G.H. Evans. European Cetacean Society, Lugano, Switzerland. 288pp.

Martin, A.R. and Rothery, P. (1993) Reproductive parameters of female long-finned pilot whales (*Globicephala melas*) around the Faroe Islands. *Rep. Int. Whal. Commn* (special issue 14), 263-304.

Martin, A.R., Reynolds, P., and Richardson, M.G. (1987) Aspects of the biology of pilot whales, genus (*Globicephala melaena*) in recent mass strandings on the British coast. *J. Zool*., (Lond.), 211, 11-23.

Malme, C.I., Smith, P.W., and Miles, P.R. (1986) *Characterisation of Geophysical Acoustic Survey Sounds*. Minerals Management Service, LA, California. Rep. no. OCS/MMS-86/0032.

Mitchell, E.D. (1975) Report of the Meeting on Smaller Cetaceans, Montreal, 1-11 April 1979, Subcommittee on Small Cetaceans, Scientific Committee, International Whaling Commission. *J. Fish. Res. Bd Can.*, 32, 889-983.

Mohl, B. and Andersen, S.H. (1973) Echolocation: high frequency component in the click of the harbour porpoise (*Phocoena phocoena* L.). *Journal of the Acoustical Society of America*, 54, 1368-1372.

Moore, S.E. and Ridgway, S.H. (1995) Whistles produced by common dolphins from Southern California Bight. *Aquatic Mammals*, 21, 51-63.

Northridge, S., Tasker, M.L., Webb, A., and Williams, J.M. (1995) Seasonal distribution and relative abundance of harbour porpoises *Phocoena phocoena* (L.), white-beaked dolphins *Lagenorhynchus albirostris* (Gray) and minke whales *Balaenoptera acutorostrata* (Lacepède) in the waters around the British Isles. *ICES Journal of Marine Science*, 52: 55-66.

Payne, P.M. and Heinemann, D.W. (1993) The distribution of pilot whales *Globicephala* spp. In the shelf-edge and slope waters of the northeastern United States, 1978-1988. *Rep. Int. Whal. Commn* (special issue 14), 51-68.

Richardson, W.J., Greene Jr., C.R., Malme, M.I., and Thomson, D.H. (1995) *Marine mammals and noise.* Academic Press, London & New York. 576pp.

Ross, D. (1976) *Mechanics of Underwater Noise*. Pergamon, New York.

Schevill, W.E. and Watkins, W.A. (1972) Intense low-frequency sounds from an Antarctic minke whale, *Balaenoptera acutorostrata*. *Breviora*, 388, 1-7.

Schevill, W.E., Watkins, W.A., and Ray, C. (1969) Click structure in the porpoise, *Phocoena phocoena*. *Journal of Mammalogy*, 50, 721-728.

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

Sturtivant, C.R., Datta, R., and Goodson, S.A. (1994) A review of echolocation research on the harbour porpoise *Phocoena phocoena* and the common dolphin *Delphinus delphis*. Pp. 164-168. In *European Research on Cetaceans - 8*. Proc. 8th Ann. Conf. ECS, Montpelier, France, 2-5th March 1994 (Ed. P.G.H. Evans). European Cetacean Society, Cambridge. 288pp.

Taruski, A.G. (1979) The whistle repertoire of the North Atlantic pilot whale (*Globicephala melaena*) and its relationship to behavior and environment. Pp. 345-368. In: *Behavior of marine animals, vol. 3: Cetaceans.* (Eds. H.E. Winn and B.L. Olla). Plenum, New York. 438pp.

Thompson, P.O., Winn, H.E., and Perkins, P.J. (1979) Mysticete sounds. Pp. 403-431. In: *Behavior of Marine Animals. Vol. 3 Cetaceans*. (Editors H.W. Winn & B.L. Olla). Plenum Press, NY.

Todd, S., Stevick, P., Lien, J., Marques, F., and Ketten, D. (1996) Behavioural effects of exposure to underwater explosions in humpback whales (*Megaptera novaeangliae*). *Canad. J. Zool*.

Urick, R.J. (1983) *Principles of Underwater Sound*. McGraw-Hill, New York.

Urick, R.J. (1986) *Ambient Noise in the Sea.* Peninsula Publishing, Los Altos, CA.

Waring, G.T., Gerrior, P., Payne, P.M., Parry, B.L., and Nicholas, J.R. (1990) Incidental take of marine mammals in foreign fishery activities off the northeast United States, 1977-1988. *Fish. Bull. U.S.*, 88, 347-360.

Weilgart, L.S. and Whitehead, H. (1990) Vocalizations of the North Atlantic pilot whales (*Globicephala melas*) as related to behavioural contexts. *Behav. Ecol. Sociobiol.*, 26(6), 399-402.

Westerberg, H. (1994) Fiskeriundersokningar vid havsbaserat vindkraftvert 1990-1993. Rapport 5 – 1994. 44pp. Goteborgsfilialen, Utredningskonteret I Jonkoping. *Sweden National Board of Fisheries*.

Westerberg, H. (1999) Impact studies of sea-based windpower in Sweden. *Technische Eingriffe in marine Lebensraume*.

Wilson, B. (1995) *The ecology of bottlenose dolphins in the Moray Firth, Scotland: A population at the northern extreme of the species' range.* PhD Thesis, University of Aberdeen.

Wilson, B., Thompson, P.M., and Hammond, P.S. (1997) Habitat use by bottlenose dolphins: seasonal distribution and stratified movement patterns in the Moray Firth, Scotland. *J. appl. Ecol.*, 34, 1365-1374.

Winn, H.E. and Perkins, P.J. (1976) Distribution and sounds of the minke whale, with a review of mysticete sounds. *Cetology*, 19, 1-11.