CETACEANS IN THE VICINITY OF ABERDEEN AND ADJACENT SEA AREAS

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INTRODUCTION The Grampian coast of Scotland and adjacent areas of the northern North Sea are relatively rich areas for cetaceans compared with other parts of the United Kingdom, with a high diversity of species recorded. Fifteen cetacean species have been recorded since 1990 in near-shore waters (within 60 km of the coast), and all have been sighted alive at least once (Evans, 1995, Evans *et al*. 2003, Sea Watch, unpublished data). Nine species (one-third of a UK total of 27 species) occur regularly, either being present year-round or as seasonal visitors to the region. The most frequently observed species in near-shore waters are the harbour porpoise *Phocoena phocoena* and the bottlenose dolphin *Tursiops truncatus*, but white-beaked dolphins *Lagenorhynchus albirostris* and minke whales *Balaenoptera acutorostrata* also occur every summer. Atlantic white-sided dolphin *Lagenorhynchus acutus*, short-beaked common dolphin *Delphinus delphis*, Risso's dolphin *Grampus griseus*, long-finned pilot whale *Globicephala melas*, and killer whale *Orcinus orca* are uncommon, but nevertheless are recorded in the northern North Sea more or less annually. The harbour porpoise and bottlenose dolphin are listed in Annex II of the Habitats Directive as species whose conservation requires the designation of Special Areas of Conservation.

Other cetacean species recorded in the region since 1990 include striped dolphin *Stenella coeruleoalba* (strandings only), northern bottlenose whale *Hyperoodon ampullattus*, Sowerby's beaked whale *Mesoplodon bidens* (stranding only), sperm whale, *Physeter macrocephalus* (live sighting of two off Peterhead in October 1998), humpback whale *Megaptera novaeangliae*, and fin whale *Balaenoptera physalus*.

Sightings plots for the four most regular species are provided in Figures 1-4, whilst Figure 5 gives plots of the eight other species recorded live in the Aberdeen area.

METHODS OF DATA COLLECTION Information on cetacean status and distribution comes primarily from the national sightings database (1973-present) maintained by the Sea Watch Foundation (SWF), and the strandings scheme organised by the Natural History Museum in London (1913-present), with input from the Scottish Strandings Scheme run from the Scottish Agricultural College at Inverness.

Systematic effort-based land watches have been carried out at several locations along the Aberdeen coast, and this is reflected in the distribution of sightings. The sites most often watched (in descending order) are Aberdeen Harbour (Torry Battery), Girdleness, Cove (Souter Head), Collieston and Stonehaven. Other sites watched (<1,000 minutes of observation) include Aberdeen Beach, Nigg Bay, Whinnyfold, Balmedie, Muchalls, Rattray Head, North Broad Craig, Slains Castle, St Cyrus, Donmouth, Doonies Yawn, and Newburgh.

Since 1998, Sea Watch has undertaken regular sea-based surveys in the region, mainly in coastal waters between Stonehaven and Aberdeen (Weir & Stockin, 2001; Weir *et al*., 2007; Canning, 2007; Sea Watch Foundation unpublished data), although watches have also been made from ferries operating from Aberdeen to Shetland & Orkney. A summary of Sea Watch effort, both land-based and sea-based, is given in Table 1.

Table 1. Summary of Sea Watch observation effort, 1993-2007

Vessel	***No. of hours of observation***
1993-97	**15.00 h**
1998-02	**138.40 h**
2003-07	**233.75 h**
Land	
1993-97	**104.75 h**
1998-02	**505.00 h**
2003-07	**850.00 h**

A major international collaborative programme, the Small Cetacean Abundance in the North Sea (SCANS) project, was conducted in the region in July 1994, in order to provide a baseline assessment of abundance of the major species (Hammond *et al*., 2002). Harbour porpoises, white-beaked and possibly Atlantic white-sided dolphins were observed throughout the northern North Sea. In the Grampian Region, there were three transect lines eastwards from the coast, although coverage in the coastal sector was very limited. This survey was repeated in July 2005 (SCANS 2), over a larger area of the Northwest European continental shelf, when there were greater numbers of sightings of harbour porpoises in the southernmost North Sea than in 1994, but fewer in the northern North Sea and east of Scotland. The results of this survey have not yet been published, but preliminary results are available. However, coverage east of the Grampian region was largely confined to an area northeast of Fraserburgh.

There have also been quite a lot of opportunistic sightings reported in the region. As with actual dedicated watches from land and sea, effort has been highest between the months of April and September when sea conditions usually are also best, so winter sightings are probably under represented.

For details of the Sea Watch national observer scheme, see Evans (1980, 1992, 1998), Evans *et al.* (2003), and Reid *et al*. (2003). As part of seabird surveys in the North Sea and English Channel, offshore sightings data were also collected during the 1980s and 1990s by JNCC's Seabirds at Sea Team (Northridge *et al*., 1995; Reid *et al.* 2003). The species status review below refers to data from all sources since the late 1990s.

STATUS & ECOLOGY The status, seasonal occurrence, and ecology of the four species of cetaceans recorded regularly in recent years around Aberdeen City and the adjacent sea areas along the Grampian coast are given below:

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, 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 uneven 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 as noted above 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 south to the Firth of Forth (particularly inner Moray Firth, Aberdeen area, and St Andrews Bay). The species is scarce in the central and southern North Sea, but it occurs seasonally along the south coast of England at particular localities. From the mid 1990s onwards, bottlenose dolphins have been seen regularly off the Aberdeen coast (see Fig. 1a-c), and photo-ID matches have shown that some if not all of the animals are part of the Moray Firth population that has extended its range southwards (Weir & Stockin, 2001; Wilson *et al.*, 2004; Canning, 2007).

There are 1,638 sightings verified as of this species in the region since 1979, of which more than 95% have been since 1993. Sightings have been mainly between Aberdeen and Stonehaven, but this undoubtedly reflects the greater survey coverage in that area. Nevertheless, within that region, there are two apparent hotspots – one around Aberdeen itself and the other between Stonehaven and Muchalls (Fig. 1). The entrance to Aberdeen Harbour itself is frequently used by bottlenose dolphins, and they commonly feed near Torry Battery and around Girdleness (Fig. 2). Seasonal patterns of occurrence have changed over the years. Between 1993 and 1997, when there were only a few sightings, these occurred mainly in large groups (Fig. 8), with sightings and group size peaking in early autumn (Fig. 10a). Since 1998, however, bottlenose dolphins have been seen in all months of the year, and in generally larger groups, with peak group sizes occurring in late winter – spring (Feb-Mar) (Fig. 8). Bottlenose dolphin sighting rates from land-based watches were highest between October and April (Fig. 10a), and from vessel surveys between October and May (although boat coverage in winter has been very limited) (Fig. 11a). The numbers of dolphins per unit effort also was highest between October and May (Fig. 12a). It is worth noting that seasonal peaks further north in the Moray Firth tend to occur in mid to late summer (June – September), i.e. the opposite pattern to what is observed off Aberdeen.

Bottlenose dolphins have an extended breeding season, but with births peaking between May and October (Evans 1980, 1998; Evans *et al*., 2003; Wilson, 1995; Grellier, 2000). They 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) (Santos *et al*., 2001). Around the entrance to the Rivers Don and Dee, dolphins have been observed pursuing salmonid fish.

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 and feeding related functions (0.2-16 kHz) (Janik, 2000). Whistles are pure tone frequency modulated calls ranging from 2-20 kHz. Clicks and whistle vocalisations can be made simultaneously. Hearing sensitivity is highest between c. 30 and 120 kHz.

International protection includes Appendix II of CMS Agreement on the Conservation of Migratory Species of Wild Animals (BONN Convention, 1983); Appendix II of BERN Convention on the Conservation of European Wildlife and Natural Habitats (applied to this species, from 1987); and Annex II of the EC Habitats Directive (1992) (prohibiting all forms of deliberate capture, killing or disturbance, especially during breeding, rearing or migration; bans the keeping, sale, or exchange of such species; and requiring that member states monitor the incidental capture and killing of all cetaceans, and carries out research on conservation measures to prevent such accidents). Like all cetacean species, it is also listed on Annex IV Animal and Plant Species of Community Interest in Need of Strict Protection of the EC 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 (Reeves *et al*., 2003) as "Data Deficient". In the UK, it receives special protection in respect of particular methods of killing or taking under The Wildlife and Countryside Act (1981) and the Wildlife (Northern Ireland) Order (1985). It is one of the species for which the Agreement on the Conservation of Small Cetaceans in the Baltic and North Seas (ASCOBANS) (1992), applies.

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 over the continental shelf from the Barents Sea south to the coast of France and Spain, although from the 1970s to 1990s, it became scarce in the southernmost North Sea, English Channel, and Bay of Biscay. Nevertheless, it remains 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 where some of the largest concentrations occur). Only small numbers occur off the south coast of England, and the declines noted in coastal areas of the southern North Sea during the 1970s, extended to and included some more northern and Atlantic sites during the early 1980s. There was a reversal in this trend during the 1990s but in the last decade, there is some evidence for a southwards shift in abundance towards the central North Sea (Evans, 1992; Evams *et al*., 2003; P.S. Hammond, *pers. comm.*, reporting the results of July 2005 SCANS II Survey).

Next to the bottlenose dolphin, the harbour porpoise is the most commonly reported cetacean species in the Grampian Region. In most regions around the British Isles, it is the most commonly observed species. In this area, there have been 1,341 sightings since 1974 (mainly from the 1990s onwards). Between 1993-97, sightings were scattered over a wide area (Fig. 3a) including offshore, but since 1998, these have been much more coastal (Figs 3b-c). Although this may partly reflect changing distribution patterns, survey effort has also been less in the last ten years and so this will likely introduce a bias. The area east of the entrance to Aberdeen Harbour has also been used a great deal by porpoises, although they have tended to keep further offshore and south of Girdleness in the vicinity of Cove Bay (Fig. 4), compared with the bottlenose dolphin. The latter is known to kill porpoises, and this may represent a spatial shift in response to increased predation risk (Canning, 2007).

Harbour porpoise mean group size has peaked in August in all three time periods, although groups were substantially larger during the 1990s compared with since then (Fig. 9a-c). The species is seen in all months of the year, although sighting rates, mean group size and numbers of individuals per unit effort reach a peak mainly around August or September, with a possible additional peak in spring (March – May) (Fig. 9, 10b, 11b, 12b; see also Weir & Stockin, 2001; Evans *et al*., 2003; Sea Watch unpublished data; Canning 2007). Besides an apparent reduction in numbers of sightings per unit effort since 2002, there has been little change in the patterns between time periods.

The main diet of porpoises is small fish (usually less than 40 cm length) such as juvenile herring, sprat, sandeel, whiting, saithe, and pollack, although particularly in winter months, prey such as dab, flounder, sole, and cod are taken (Santos & Pierce, 2003). Breeding occurs mainly between May and August, with a peak in June, though some can be as early as March (Lockyer, 1995, 2003).

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; Akamatsu *et al*., 1992; 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 178 and 205 dB re 1µPa at 1 m (Villadsgaard *et al*., 2007). The contexts in which these click trains are used are not well understood but intense buzzes have been related to feeding (Verboom & Kastelein, 1997, Verfuß *et al*., 2005]. Hearing sensitivity is highest between c. 10 and 150 kHz.

International protection includes Appendix II of CMS Agreement on the Conservation of Migratory Species of Wild Animals (BONN Convention, 1983); Appendix II of BERN Convention on the Conservation of European Wildlife and Natural Habitats (applied to this species, from 1987); and Annex II of the EU Habitats Directive (1992) (prohibiting all forms of deliberate capture, killing or disturbance, especially during breeding, rearing or migration; banning the keeping, sale, or exchange of such species; and requiring that member states monitor the incidental capture and killing of all cetaceans, and carries out research on conservation measures to prevent such accidents). Like all 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 (Reeves *et al*., 2003) as "Vulnerable". 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). It is one of the species for which the Agreement on the Conservation of Small Cetaceans in the Baltic and North Seas (ASCOBANS) (1992), applies.

White-beaked Dolphin (*Lagenorhynchus albirostris*) The white-beaked dolphin is restricted to temperate and sub-polar seas of the North Atlantic. It occurs over a large part of the northern European continental shelf (mainly in waters of 50-100 m depth, and almost entirely within the 200 m isobath), its distribution extending northwards to northern Norway, Iceland, the Greenland Sea and central west Greenland.

The species is common in British and Irish waters, and is found most abundantly in the central and northern North Sea across to north-west Scotland, although it also occurs less commonly in the southern North Sea, and occasionally in Western and Southern Ireland, St George's Channel, English Channel, and northern Bay of Biscay. From line transect surveys in July 1994 (Hammond *et al.*, 2002), a population estimate of 7,856 white-beaked dolphins (4,032-13,301) was made for the North Sea and Channel. An abundance estimate of 11,760 (5,867-18,528) dolphins was obtained when all *Lagenorhynchus* (i.e. white-beaked and Atlantic white-sided dolphins) sightings were combined (including those whose specific identity was not known).

In the northern North Sea, white-beaked dolphins typically occur mainly offshore and in late summer between June and September (particularly in August); these are also the peak months for sightings rates and individual rates when corrected for effort (Northridge *et al*., 1995; Evans *et al*., 2003; Reid *et al.*, 2003). It is rarely reported between November and April. However, in recent years, the species may be exhibiting a shift northwards. During the SCANS II survey in July 2005, only one sighting of white-beaked dolphins was made south of 55^{o}N. A similar reduction in sightings was observed in the Sea Watch database, comparing sightings during the 1980s-90s (Evans, 1998, 1992; Northridge *et al*., 1995; Evans *et al*. 2003) with those since 2002.

Off the Grampian coast, white-beaked dolphins were seen regularly over a wide area both near shore and offshore during the 1990s (Fig. 5a). Between 1998 and 2002, sightings were confined to the coastal strip (although effort offshore was also reduced somewhat) (Fig. 5b). Between 2003-07, there were rather more sightings (with the exception of 2007, when numbers of sightings decreased once more) (Fig. 5c). A total of 336 sightings have been reported in the region since 1978 (mainly since 1992). Sighting rates in the region peak during July/August for land-based watches (Fig. 10c) and between June and August from vessel-based surveys (Fig. 11c), which are also the months when numbers of individuals per unit effort peak (Fig. 12c). As elsewhere in UK coastal waters, white-beaked dolphins appear to be very seasonal, coming into the region almost exclusively in mid to late summer (Evans *et al*., 2003; Evans & Smeenk, 2008).

White-beaked dolphins feed upon mackerel, herring, cod, poor-cod, sandeels, bib, whiting, haddock, and hake, as well as squid, octopus, and benthic crustaceans (Canning *et al*., 2008; Evans & Smeenk, 2008). The region is used both for feeding and breeding. They breed mainly between May and August, although some may occur also in September and October (Evans & Smeenk, 2008).

Vocalisations poorly known but include whistles of 6.5 to at least 15 kHz frequency (often around 8 kHz), with average source levels (SL) of 180 dB re 1 µPa @ 1 m, and echolocation clicks of up to at least 325 kHz, with click bursts of 100-750 pulses per second, and maximum SL of 214 dB re 1 µPa @ 1 m (mean SL = 204 dB, mean inter-click interval = 51 ms) (Watkins *pers. comm*., Mitson & Morris 1988, Mitson 1990, Reeves *et al.*, 1999b, Rasmussen *et al.*, 1999).

International protection includes Appendix II of CMS Agreement on the Conservation of Migratory Species of Wild Animals (BONN Convention, 1983); Appendix II of BERN Convention on the Conservation of European Wildlife and Natural Habitats (applied to this species, from 1987); and Annex IV Animal and Plant Species of Community Interest in Need of Strict Protection of the EC 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). Its status is listed by IUCN (Reeves *et al*., 2003) as "Least Concern". In UK, it receives protection under The Wildlife and Countryside Act (1981) and the Wildlife (Northern Ireland) Order (1985). It is one of the species for which the Agreement on the Conservation of Small Cetaceans in the Baltic and North Seas (ASCOBANS) (1992), applies.

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 1980s, with populations concentrated in the northern North Sea, and around North and West Scotland.

The only published population estimate for minke whales in UK waters is from the North Sea, English Channel and Celtic Sea; the line transect survey (SCANS I) in July 1994 estimated 8,450 (95% C.I. 5,000-13,500) (Hammond et al. 2002). A more extensive line transect survey (SCANS II) over the NW European continental shelf in July 2005 gave an overall estimate of 16,395 (including 10,500 in equivalent area as 1994) (P.S. Hammond, *pers. comm.*). The species is subject to whaling in Norwegian waters and to a lesser extent off Iceland and Greenland. Since 2006, the annual catch quota set by the Norwegian government has been 1,052 whales, but the numbers actually caught have been much less.

A total of 105 sightings of minke whales have been reported since 1981 (most from the 1990s onwards). Minke whale sightings are widely distributed through the region, also occurring close to the coast particularly between Stonehaven and Aberdeen (Fig. 6). There is no indication of a distributional shift between time periods (Fig. 6a-c), the increase in coastal sightings almost certainly being the result of increased effort there in recent years.

From land-based watches, minke whales have been sighted only in the months of June to August, with a peak in sighting rates in July-August (Fig. 10d). Vessel-based surveys have recorded porpoises between March and August, with peak sighting rates in March and June-August (Fig. 11d), and this reflected also in the numbers of individuals per unit effort seen which also peak in March and June-August (Fig. 12d). The number of minkes sighted per unit effort was similar in the period 2004-07 compared with 1999-2004, but sightings occurred in more months (Fig. 12d).

Elsewhere around the British Isles, most sightings also 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; Evans *et al*., 2003; Anderwald & Evans, 2007). In the autumn there appears to be a general offshore movement, possibly associated with breeding that occurs sometime between autumn and spring; however, breeding locations are unknown. There is no information on whether any more extensive migration takes place (Anderwald & Evans, 2007).

The species is most commonly seen singly or, less commonly, in loose groups of up to three; in late summer in northern and northwest Britain, loose feeding aggregations of up to 15 animals may form.

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, particularly in polar regions (Nordøy *et al*., 1995; Olsen & Holst, 2001; Pierce *et al*., 2004). 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).

EFFECTS OF PILE DRIVING UPON CETACEANS IN VICINITY OF ABERDEEN HARBOUR

Bottlenose dolphins, harbour porpoises, white-beaked dolphins and minke whales all occur in the immediate vicinity of the entrance to Aberdeen Harbour. Of those, only the bottlenose dolphin has been seen regularly moving inside the harbour walls, generally in pursuit of fish (probably salmonids, but also may include eels) in the River Dee.

The main activity in the South Side Aberdeen Harbour development with potential impact upon cetaceans will be pile driving, and so this section concentrates upon examining that impact so as to assess risk to species like the bottlenose dolphin.

Assuming that both percussive and vibratory pile driving will be undertaken (similar to the construction activities in the Albert Basin of Aberdeen Harbour in 2005), we will compare sound source levels from that operation with those obtained elsewhere using similar procedures. In that instance (but also for most similar shore construction activities), sheet piles were initially driven into the substrate by vibration, and then to full depth by a sequence of hammer blows (Urquhart *et al*., 2006). In the monitoring study, sound pressure levels (SPLs) generated by pile driving in water were measured using a calibrated hydrophone suspended one metre above the bottom, by means of a subsurface float, and expressed as average (root mean square, rrms) levels in decibels relative to a reference level of one micropascal (dB re 1µPa) as is usual in studies of this nature. Short duration impulsive sounds generated by the individual hammer blows were measured by calculating peak SPL, the mms pressure measured over the time period that contained 90% of the sound energy (mms impulse), and the sound exposure level (SEL) expressed in dB re 1µPa^2.s. SPLs were converted to SL by normalisation to an equivalent noise level at a distance of 1 m, assuming cylindrical spreading.

Background noise levels in the harbour (and within the river Dee itself) were high, mainly from shipping, in the region of 118-149 dB re 1µPa mms over a frequency bandwidth of 10 Hz – 10 kHz. Vibro-piling generated SPLs within the harbour ranging from 142-155 dB re 1µPa mms and Sls between 175-185 dB re 1µPa mms. SPLs generated in water by percussive pile driving were high and variable depending on the pile type, the substrate being penetrated, the distance from the source, and whether a bubble curtain was in operation. Measured SPLs within the harbour ranged from 154-176 dB re 1µPa peak to peak, with SELs of between 129-154 dB re 1µPa^2.s, without a bubble curtain in operation. The estimated SLs ranged from 176-202 dB re 1µPa. At >220 m away in the river Dee itself, percussive sound levels ranged from 162-173 dB re 1µPa peak to peak with SPLs of between 129-150 dB re 1µPa^2.s. The main energy generated by the percussive pile extended above 10 kHz close to the source, but with most of the energy below 2 kHz. Due to shallow water sound propagation loss, the higher frequencies decayed rapidly, leaving the predominant frequencies below 1 kHz.

A bubble curtain was successful in reducing the peak amplitude of the sound from the pile driver, by up to 8 dB, and particularly in reducing the high frequency content of the sound, although it did not reduce energy at the lower frequencies, especially at a distance from the source (Urquhart *et al*., 2006).

The present authors do not know the plans for the proposed South Side Harbour development in any detail, and so it is not possible to infer what SPLs or SELs will be generated by the project. However, the levels monitored in the area in 2005 can be compared with those obtained during other pile driving activities elsewhere. A summary of some of these, including those where potential impacts upon marine mammals was assessed, is given in Table 2.These include pile driving for a variety of purposes ranging from harbour development to bridge construction.

Table 2. Source levels (SLs) and/or pressure levels (SPLs) measuring during pile driving activities in various parts of the world

Activity	Estimated SL dB_{mms} re 1µPa	SPL dB re 1µPa	Peak frequency	Location	Reference
Pile re-striking	-	197-211 (peak) 182-195 (mms)	<1 kHz	San Francisco bridge	Thorson & Goldstein 2002, Reyff 2003
Impact piling	-	206 (peak) @ 50m 195 (rms) @ 50 m	-	San Francisco bridge	Thorson 2004, Thorson & Reyff 2004
Pile ramming	-	196 @ 103m, 167 @ 358m	-	San Francisco bridge	Woods *et al.* 2001, CALTRANS 2001
Impact piling	218 @ 1m	170 @ 250m	400 Hz	Hong Kong airport	Würsig *et al.* 2000
Vibratory piling	183 @ 1m	-	-	Southampton ferry terminal	Nedwell *et al.* 2003

The values obtained here, although not directly comparable because of different local environmental conditions, give some idea of variability in sound pressure levels at particular ranges. They are generally of the same order as observed in the 2005 Aberdeen Harbour development. Together, they suggest that source levels from impact pile driving are in the order of 218-227 dB_{pp} re 1µPa @ 1 metre, comprising short (100-200 ms) but intense impulses with maximum overall energy <1 kHz, but some components from ramming impulses up to 100 kHz. It is important to note that the maximum SPL, as well as the spectral content, strongly depend on the bottom substrates. Recordings from installation into hard bottom substrate showed SPLs of up to 262 dB re 1µPa @ 1 metre (Lucke *et al*., 2006) In the Aberdeen Harbour area, sound transmission loss is likely to be less to seaward compared with in the river Dee itself because of greater water depths.

The extensive studies conducted during work on the San Francisco-Oakland Bay Bridge focused upon potential impacts on harbour seals and California sea lions (CALTRANS, 2001; Thorson & Goldstein, 2004; Thorson 2004; Thorson & Reyff, 2004). Generally, results indicated limited short-term effects in the form of startle responses and temporary displacement of harbour seals at haul-out sites. Similar limited effects upon grey and harbour seals were found from pile driving activities around the offshore wind farms at Nysted and Horns Reef (Teilmann *et al*., 2006). Harbour porpoises, on the other hand, showed both short-term and long-term effects in the form of increased waiting times and actual displacement (Tougaard *et al*., 2003, 2005: Carstensen *et al*., 2006; Teilmann *et al*., 2006). The pile driving activities in San Francisco and Hong Kong were accompanied by the deployment of a bubble curtain as a mitigation measure. This has the effect of shrouding the sound by creating an impedance mismatch with a curtain of air bubbles. By constantly pumping air through a perforated tube located around the base of a given sound source (e.g. a pile that is to be rammed into the ground), it is possible to create a bubble curtain, which effectively reduces the noise level outside it by scattering and resonance effects. Several types of bubble curtain have been developed and tested for their potential ability to mitigate effects on marine organisms.

The bubble curtain used during construction work in waters off Hong Kong was generated by single hoes (inner diameter 50 mm) resulting in a single layered, unconfined bubble curtain. The broadband pulse levels of the percussive hammer blows were reduced at distances of 250 m to 1 km in the broadband (from 100 Hz to 25.6 kHz) by about 3-5 dB, with greatest reduction in the frequency range 400 Hz to 6.4 kHz (Würsig *et al*., 2000). However, its effects on cetaceans in the neighbourhood were not actually tested.

In San Francisco, a simple ring system was first used, creating a single unconfined layer of bubbles around the test pile (CALTRANS, 2001). This did not reduce the maximum SPL, but it did reduce the signal components above 800 Hz. A fabric barrier system with aerating system was then used to provide a constant, confined bubble curtain resistant also to currents. A large metal frame was used to hold the two-layered fabric in position. This method reduced the maximum SPL by as much as 10-25 dB, and also effectively reduced the components above 800 Hz. When in place, the authors reported that three California sea lions observed near the pile driving site responded to the ramming noise by rapidly leaving the area, regardless of whether a fabric bubble curtain was used or not (CALTRANS, 2001). No sea lions were observed during the use of the simple bubble curtain. Since then, a two-ring bubble curtain has been developed and tested, and shows signs of being more effective.

Recently, a bubble curtain was deployed at Kerteminde in Denmark close to the Fjørd & Baelt Centre which houses three harbour porpoises in a facility that receives water directly from the sea. Harbour developments in the area resulted in pile driving activities that potentially could affect the porpoises. In fact, the porpoises showed strong aversive reactions upon the start of the piling activities. Received SLs of 183 dB re 1µPa @ 1 metre (peak) were observed just outside the enclosure with an Energy Flux Density of 154 dB re 1µPa^2.s (Lucke *et al*., 2007). In order to reduce the sound exposure for the animals, a 40 m long air bubble curtain was constructed in a direct path between the piling site and the opening of the pool. Attenuation of the ramming impulse sound was observed in the range of 11-19 dB in signal peak and 13-19 dB in the impulse energy. No further adverse reactions of the animals to the ramming a ctivities were observed when the bubble curtain was active (Lucke *et al*., 2007). During a later experiment, additional sound protection measures were required to protect the porpoises from being exposed to a nearby airgun sound source. A floating pen was therefore covered with a double layer of closed cell foam. A reduction in received SPL of up to 28 dB was observed at frequencies up to 22.4 kHz. To further increase sound reduction, a bubble curtain was also placed around this pen. Using both methods, the three harbour porpoises showed no adverse behavioural reaction to the proximity of a close proximity airgun transmission, suggesting this could be a useful mitigation measure to employ in future in the vicinity of pile driving.

Studies of actual effects of pile driving upon cetaceans are very limited. However, an increasing number of thresholds exist for injury and hearing impairment of individuals. The most relevant values at present are those of the US National Research Council, which places these at RLs of 180 dB for cetaceans and 190 dB for seals. The German government (through the Federal Environment Agency), in the context of pile driving activities associated with the offshore wind farm industry, has recently recommended that at a distance of 750 m from the noise source, SPLs should not exceed 160 dB re 1µPa (Künitzer, 2006). And maximum values should not exceed 10 dB above the mean sound level. In those circumstances, relevant mitigation measures should be applied to ensure that no marine mammals are within the area exceeding 160 dB re 1µPa. They further instruct that compliance with these conditions should be demonstrated by measurements. Considering potential negative behavioural responses widely reported at RLs of 160-180 dB (and Sound Energy levels of 145 dB), and temporary threshold shifts (TTS) at SELs of 183 dB (see many references in Richardson *et al*., 1995; Evans & Nice, 1996; Würsig & Evans, 2002; National Research Council, 2003; Nowacek *et al*., 2007), we recommend a similar approach for minimising impacts upon cetaceans from the Aberdeen Harbour Development.

SUMMARY & CONCLUSIONS

Fifteen cetacean species have been recorded along the Grampian coast since 1990, making the region one of the richest for cetaceans in the UK. Of these, nine have been recorded regularly, although only four are considered significant members of the coastal marine mammal community in the vicinity of Aberdeen Harbour. These are bottlenose dolphin, harbour porpoise, white-beaked dolphin and minke whale. The first two are given special conservation status under the EU Habitats & Species Directive. Different cetacean species exhibit different seasonal peaks of occurrence. Bottlenose dolphins can be seen year round but peak occurrence and peak numbers both take place between October and May. Harbour porpoises also may be seen year round, but with peak occurrence and numbers in August – September. White-beaked dolphins are much more seasonal, with few sightings outside June – August. Minke whales are also seasonal, with no sightings outside March – August, and most between June and August. Only the bottlenose dolphin moves regularly into the harbour area between the piers.

Monitoring of pile driving activities clearly should take place. It is recommended that noise measurements be conducted over a frequency range of up to 100 kHz since this overlaps frequency levels used by bottlenose & white-beaked dolphins as well as harbour porpoise. From a biological point of view, it should be emphasized that averaged levels will be of limited use, while the peak levels and energy flux density of the impulses will be much more relevant.

Mitigation measures to reduce received levels of sound should be put in place. These should at least take the form of a bubble curtain, preferably also with deployment of a closed cell foam layer seaward of the activity. Other possible sound mitigation measures include isolation piles and cofferdams, although these may not be practical in this situation. Behavioural effects upon fish should also be considered for its potential impact upon bottlenose dolphins that use the area for feeding. Pile driving should ideally take place outside peak periods of occurrence of bottlenose dolphins, although this could then overlap with some of the other cetacean species that may use the entrance to Aberdeen Harbour. Possible compromise periods would be April or September.

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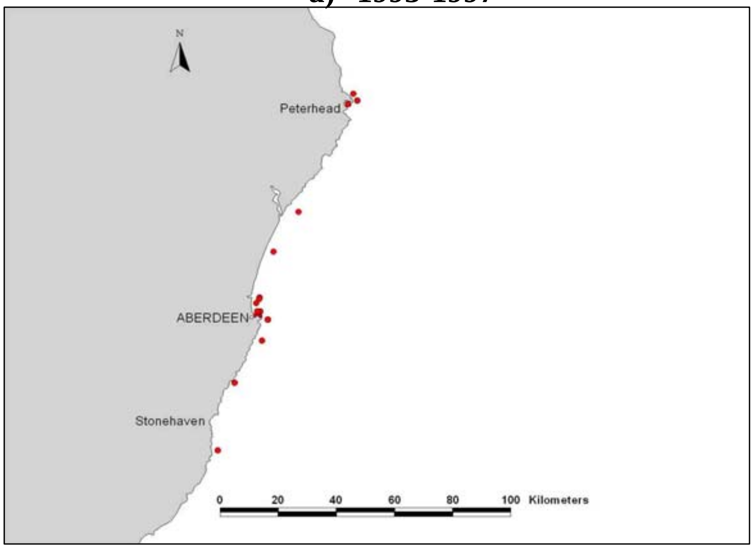
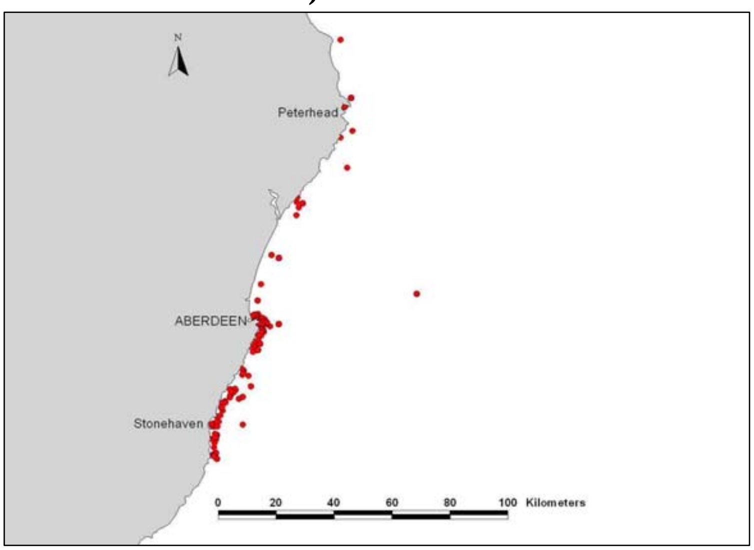
Fig. 1. Distribution of Bottlenose Dolphin Sightings

a) 1993-1997



b) 1998-2002



c) 2003-2007

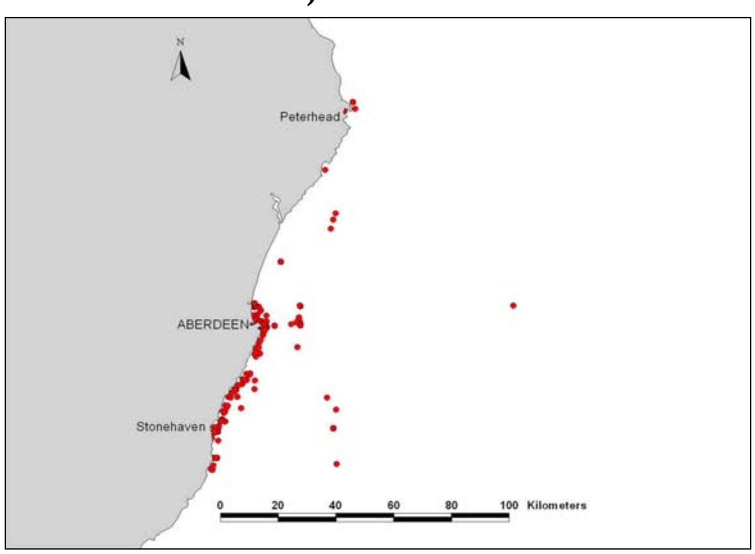


Fig. 2. Distribution of Bottlenose Dolphin Sightings around Aberdeen Harbour

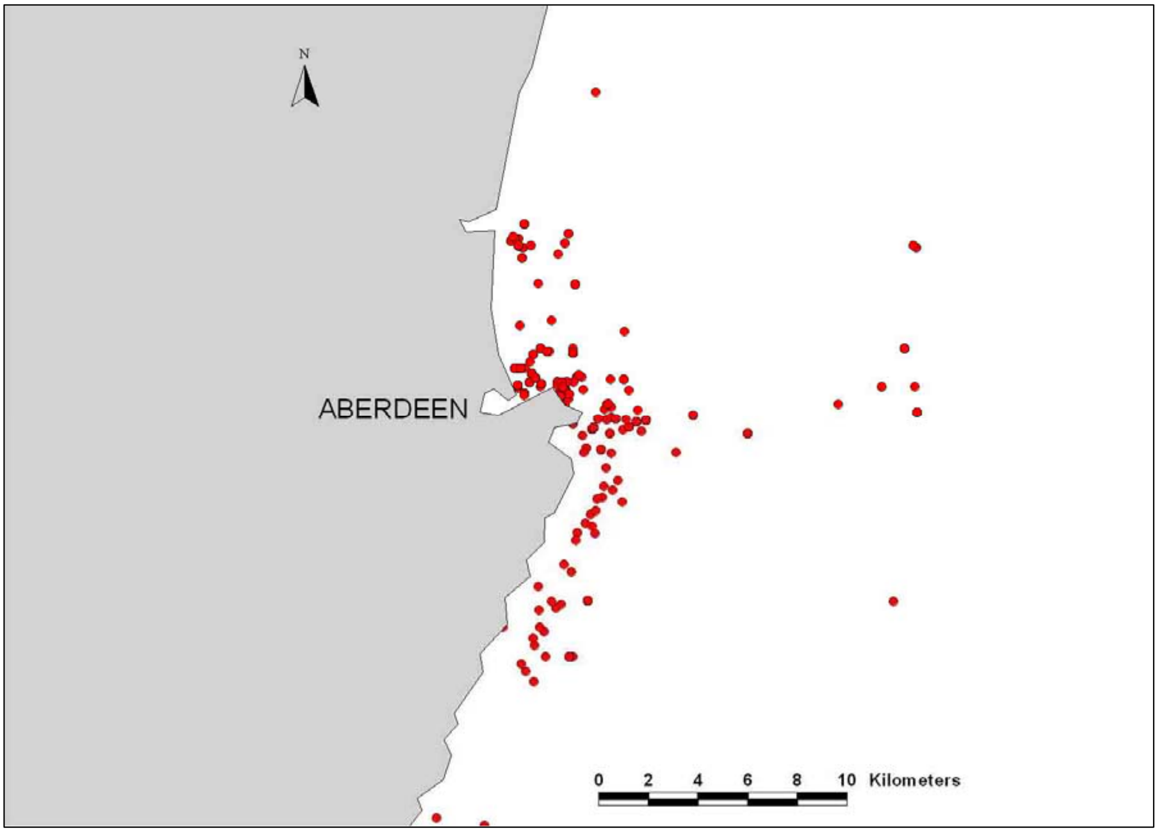
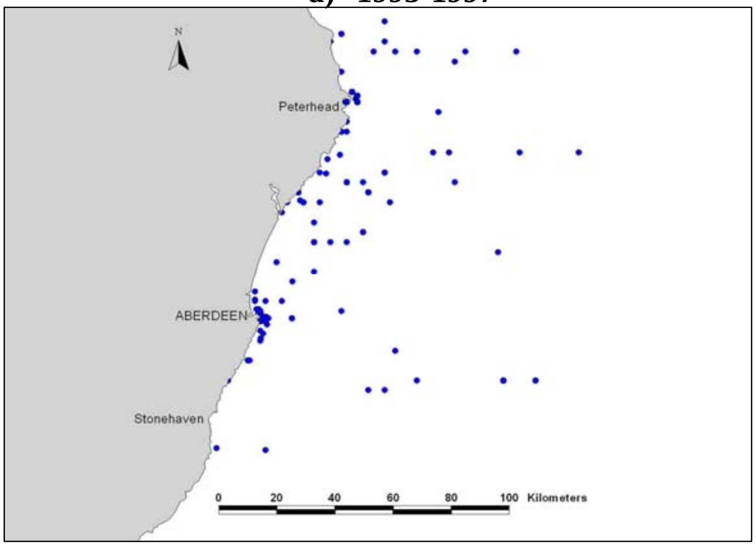
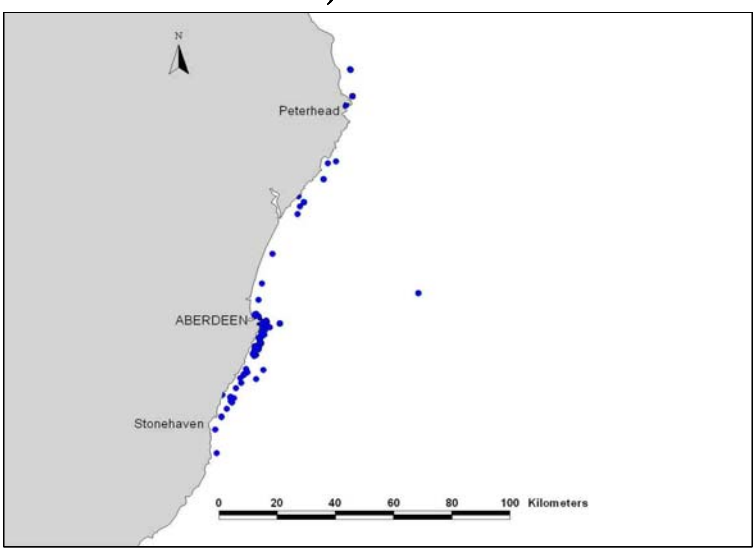


Fig. 3. Distribution of Harbour Porpoise Sightings

a) 1993-1997



b) 1998-2002



c) 2003-2007

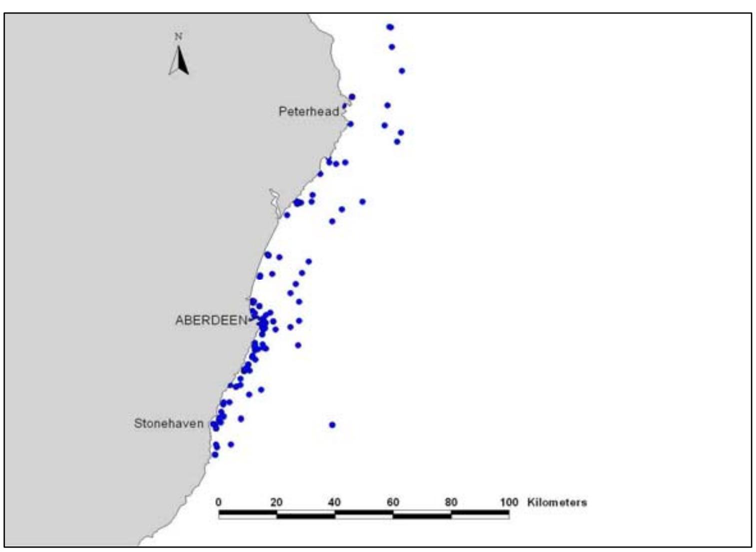


Fig. 4. Distribution of Harbour Porpoise Sightings around Aberdeen Harbour

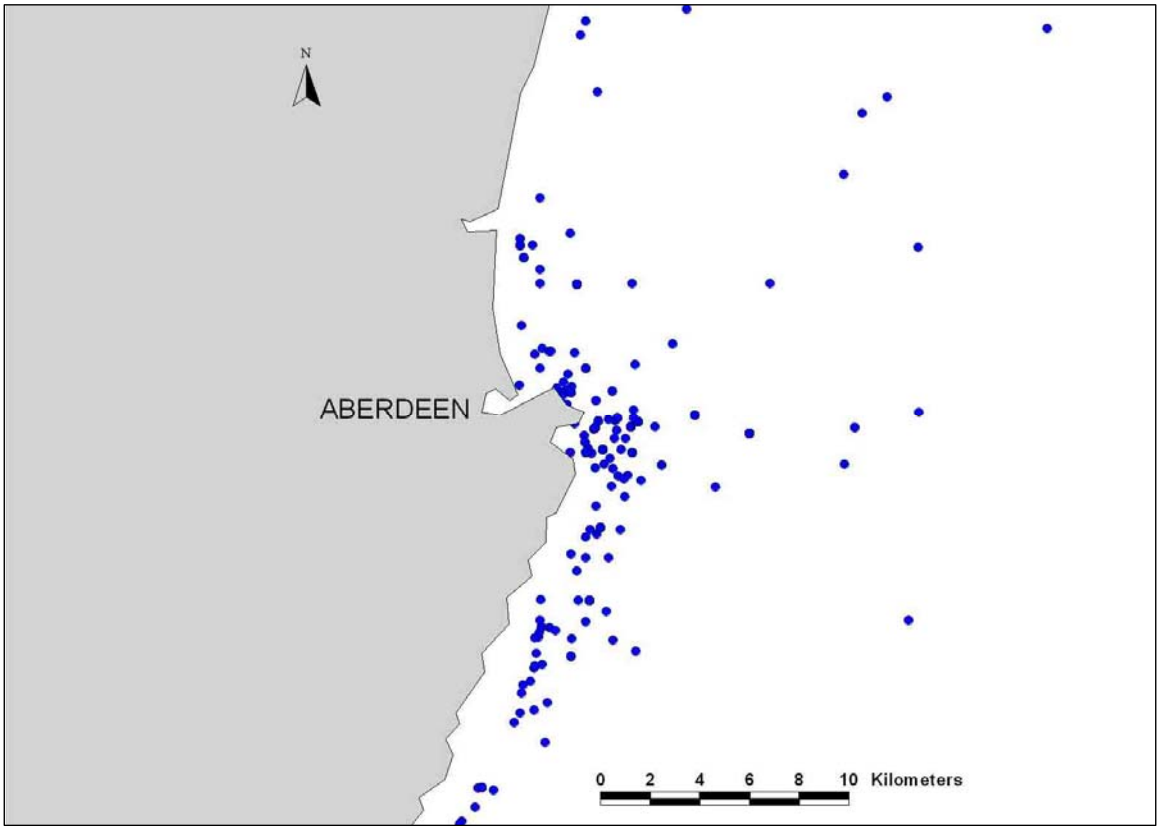
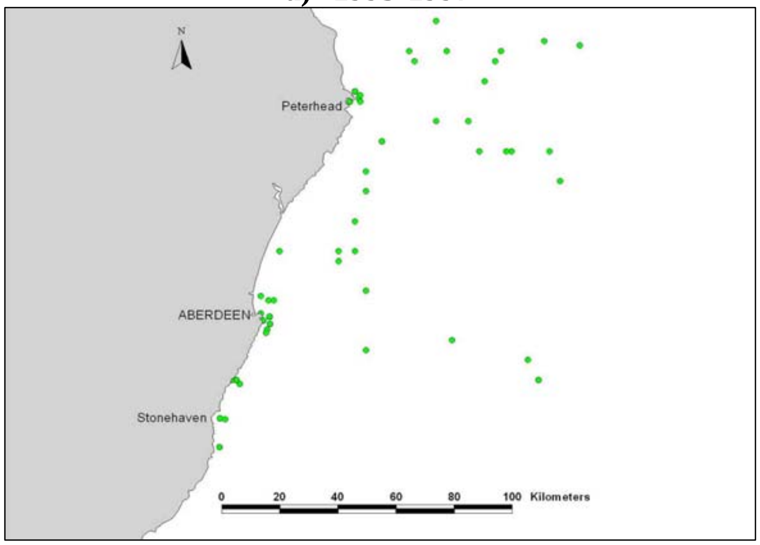
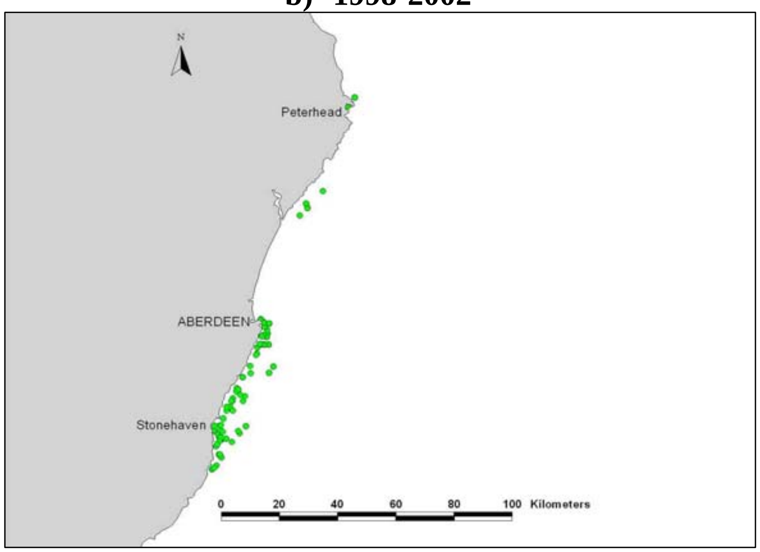


Fig. 5. Distribution of White-beaked Dolphin Sightings

a) 1993-1997



b) 1998-2002



c) 2003-2007

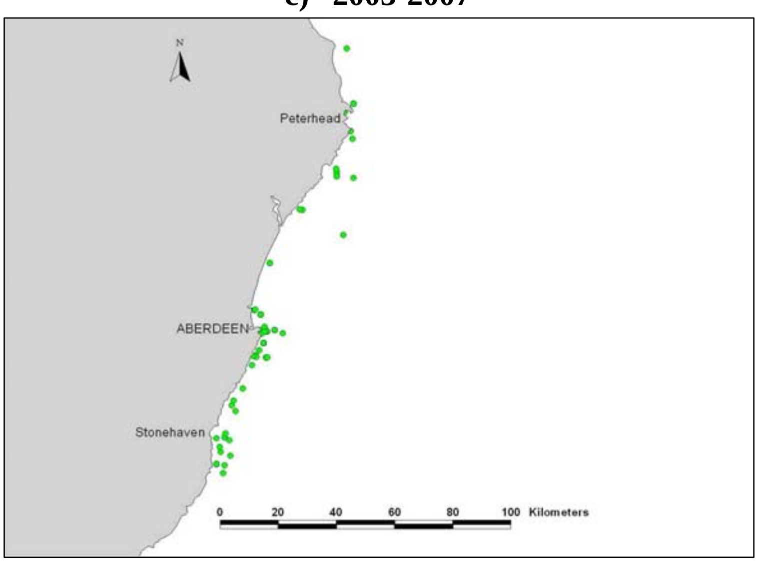
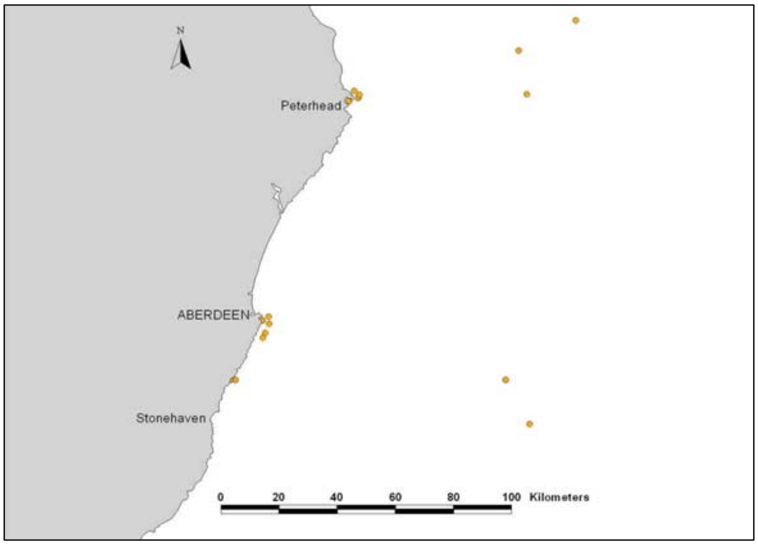
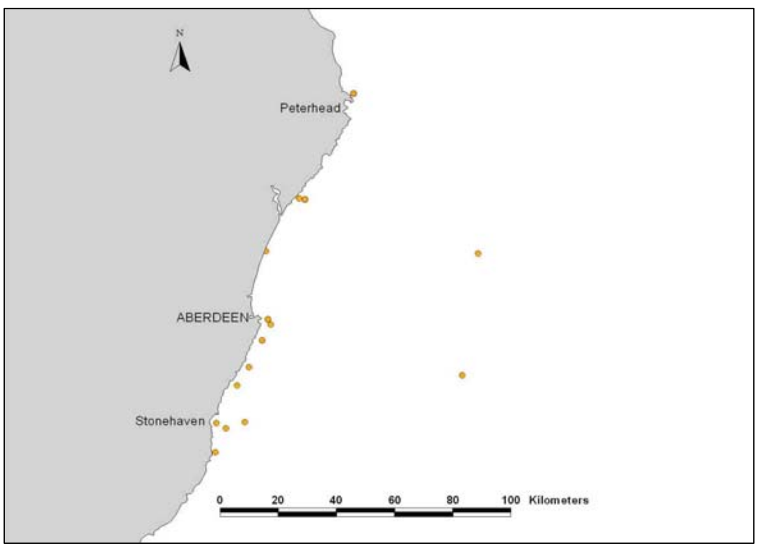


Fig. 6. Distribution of Minke Whale Sightings

a) 1993-1997



b) 1998-2002



c) 2003-2007

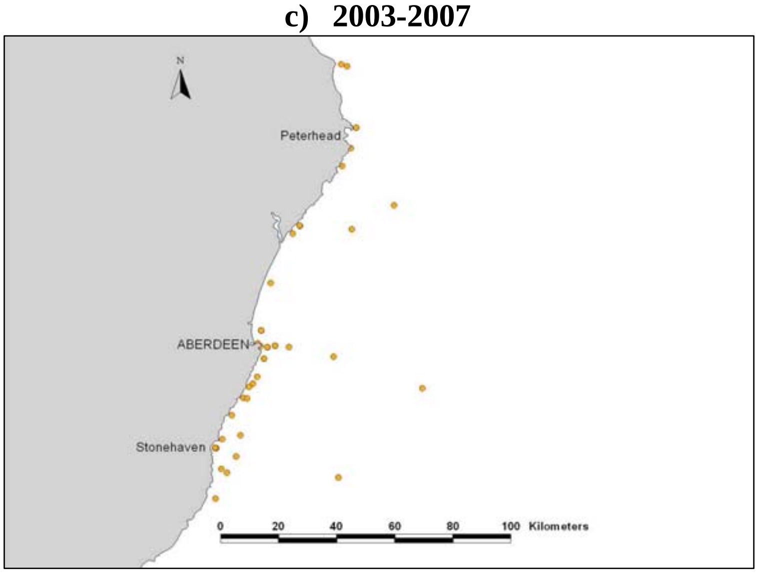


Fig. 7. Distribution of Other Cetacean Species

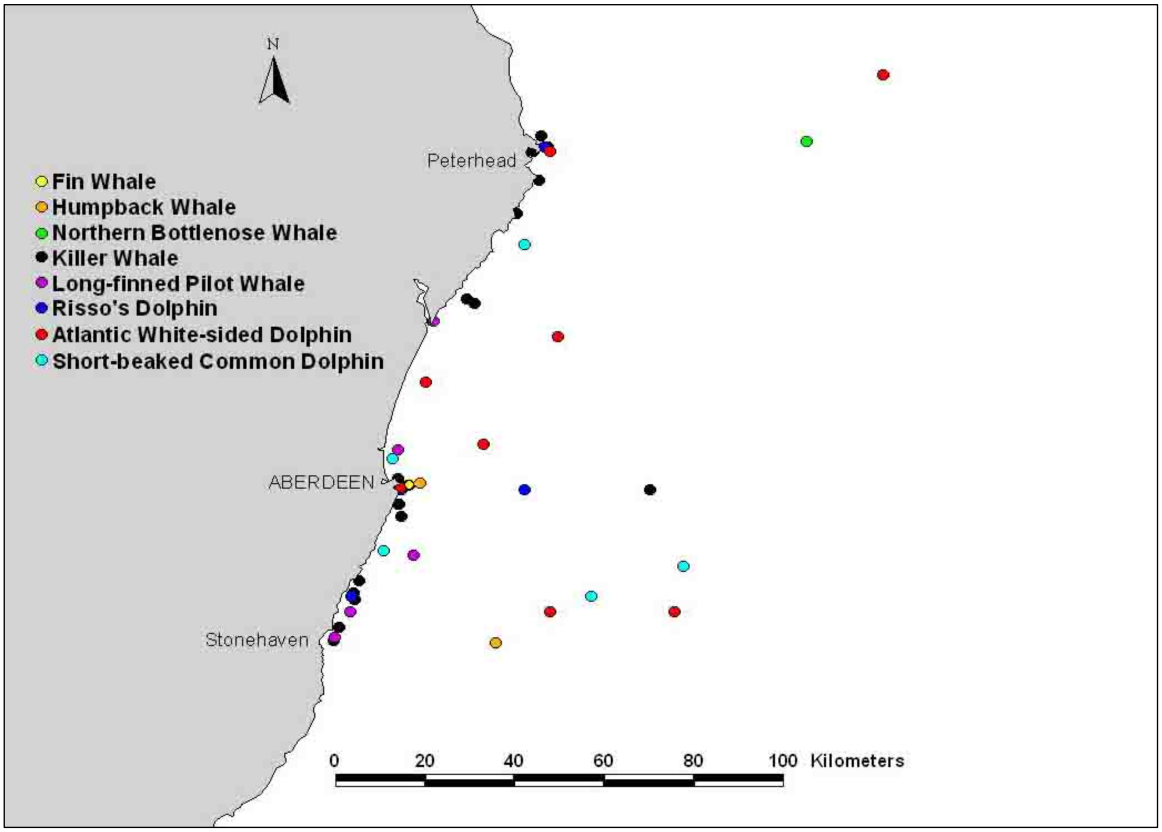


Fig. 8. Seasonal Variation in Bottlenose Dolphin mean group size: From Land-based Watches

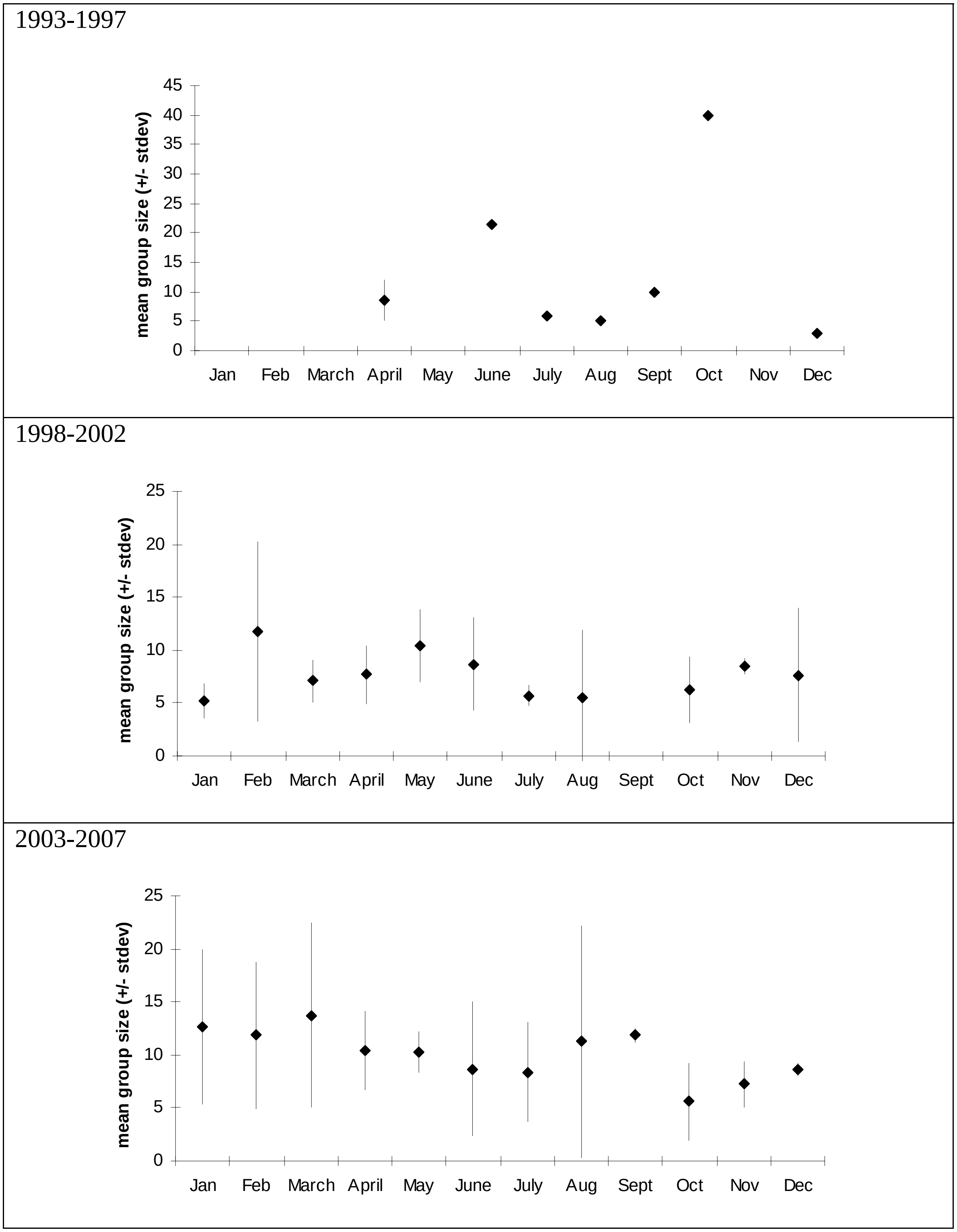


Fig. 9. Seasonal Variation in Harbour Porpoise mean group size: From Land-based Watches

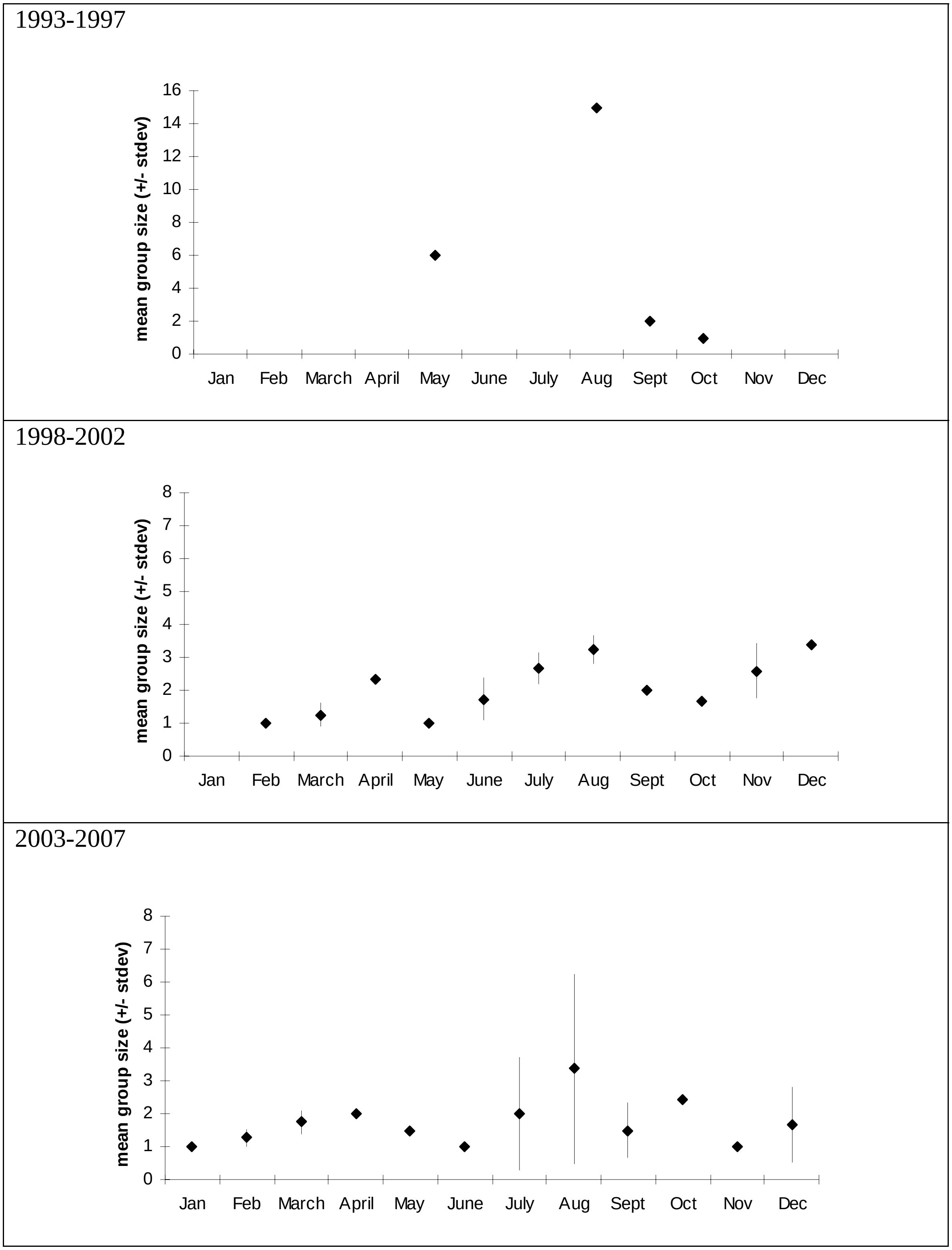


Fig. 10(a). Seasonal Variation in Bottlenose Dolphin Sighting Rates: From Land-based Watches

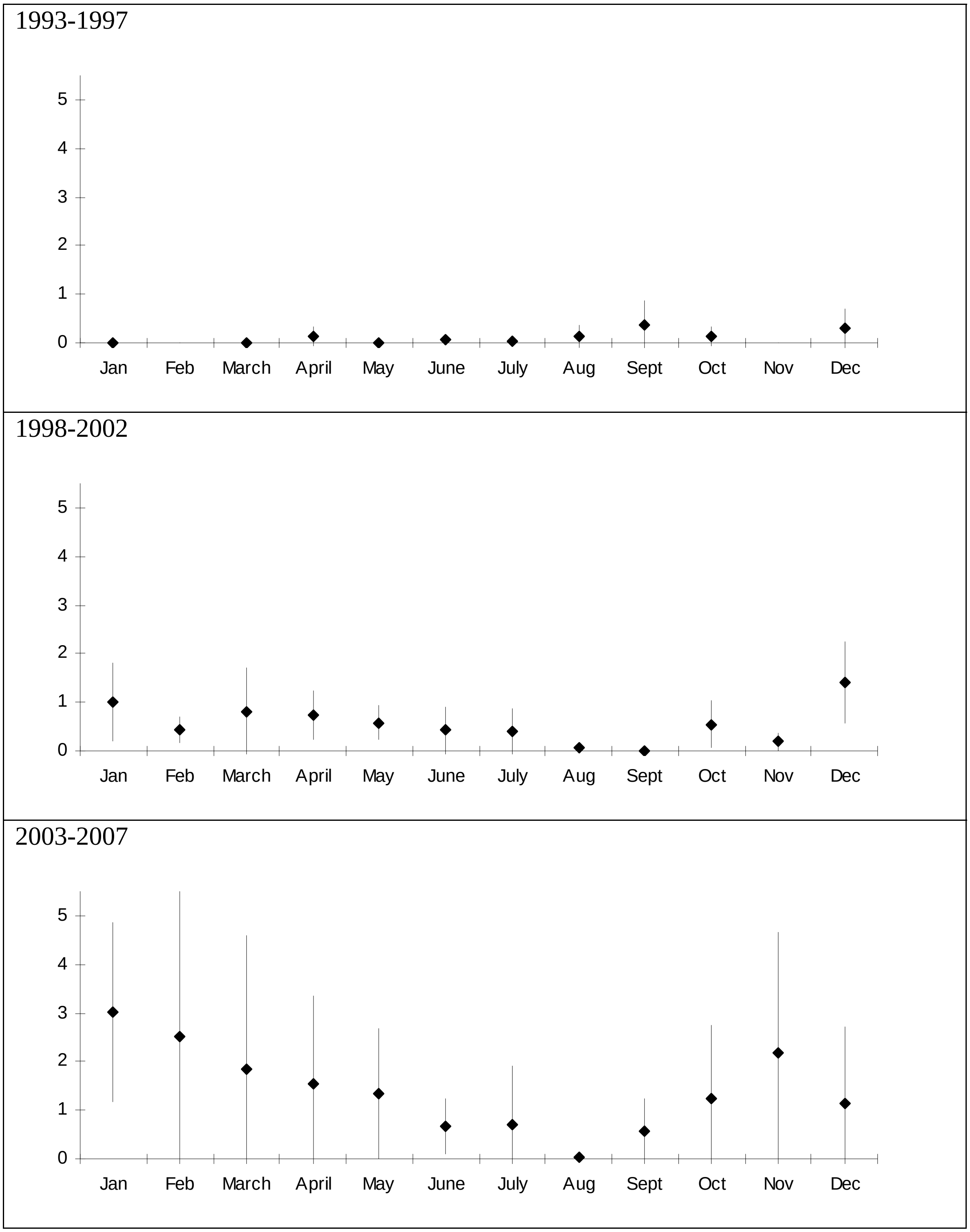


Fig. 10(b). Seasonal Variation in Harbour Porpoise Sighting Rates: From Land-based Watches

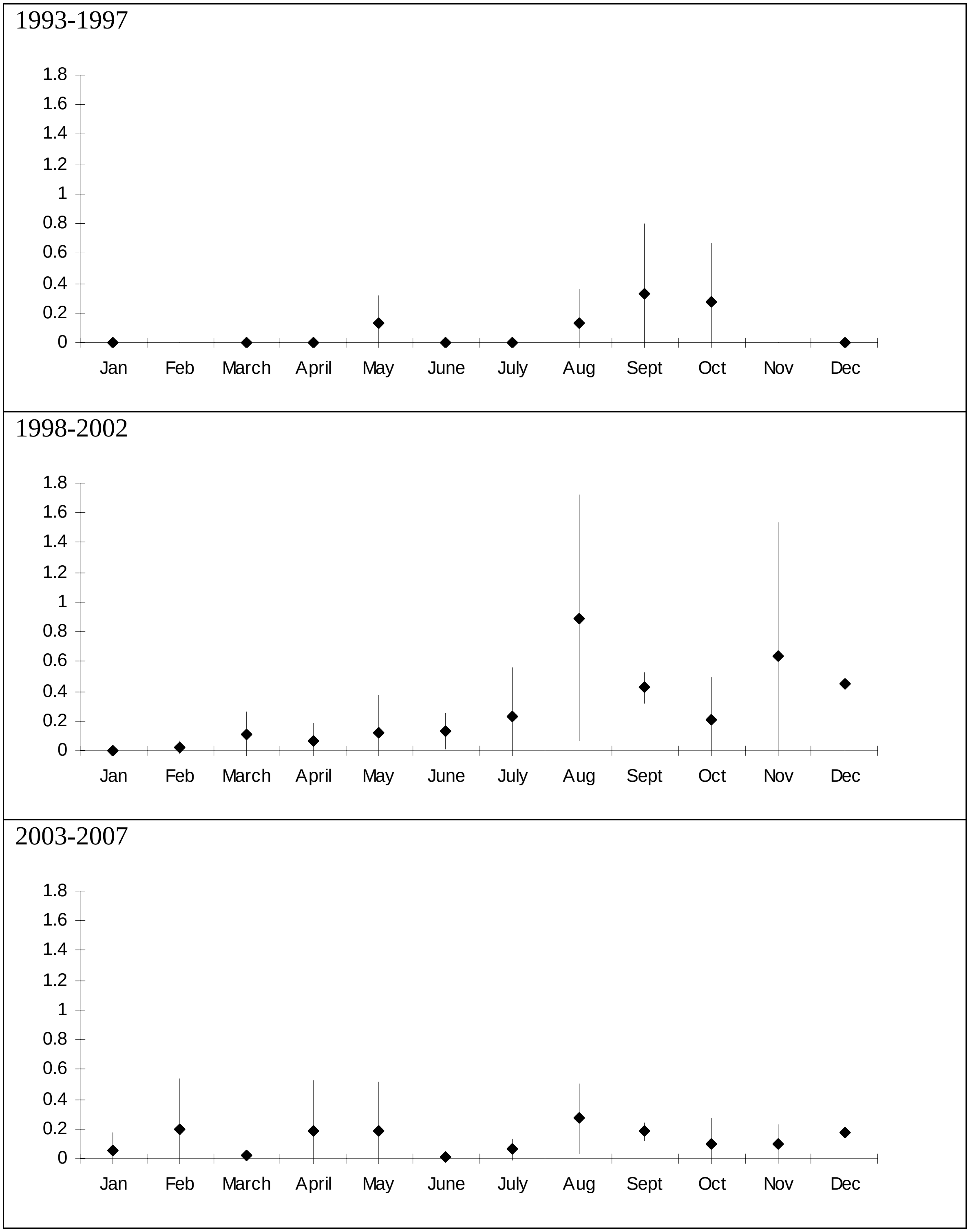


Fig. 10(c). Seasonal Variation in White-beaked Dolphin Sighting Rates: From Land-based Watches

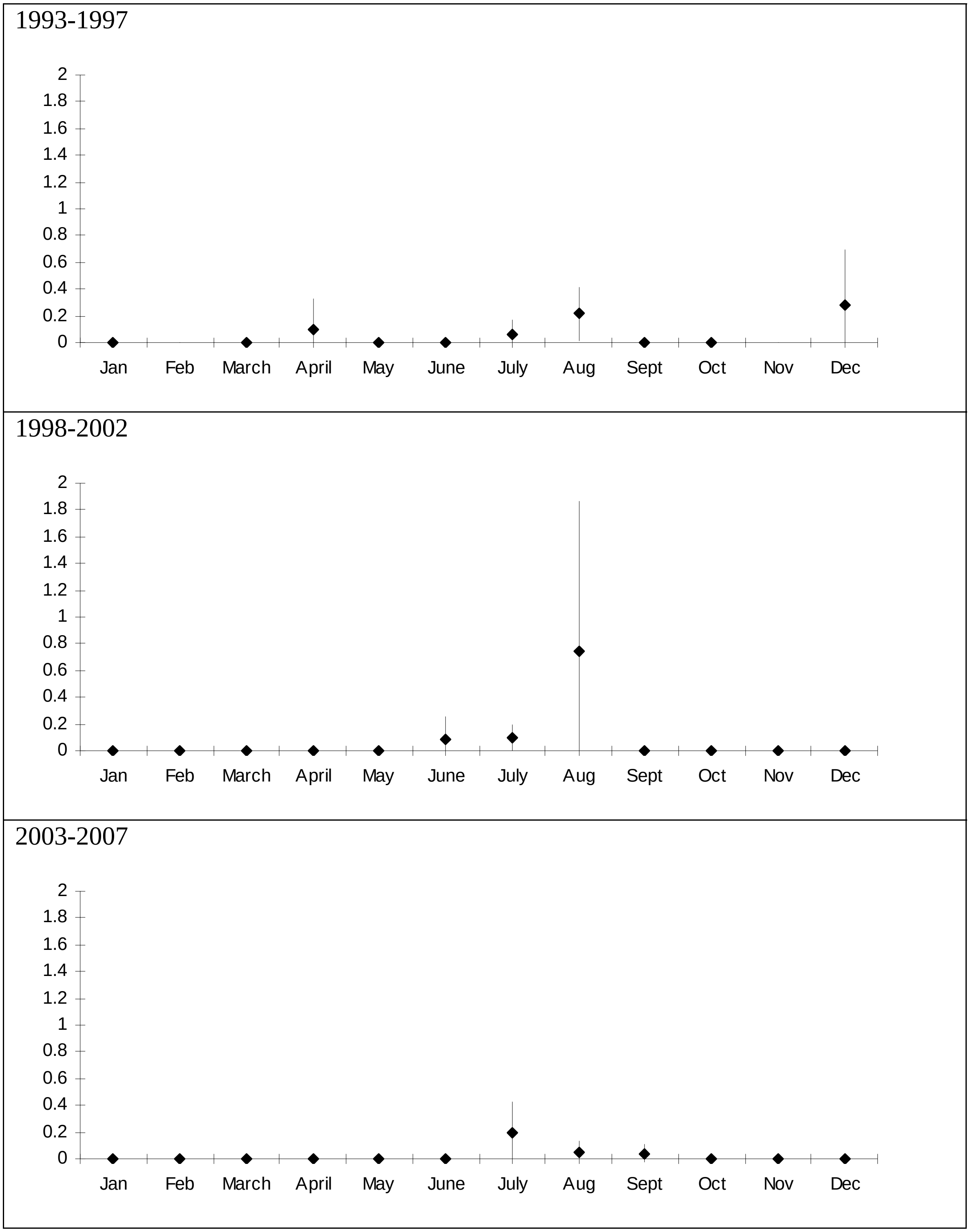


Fig. 10(d). Seasonal Variation in Minke Whale Sighting Rates: From Land-based Watches

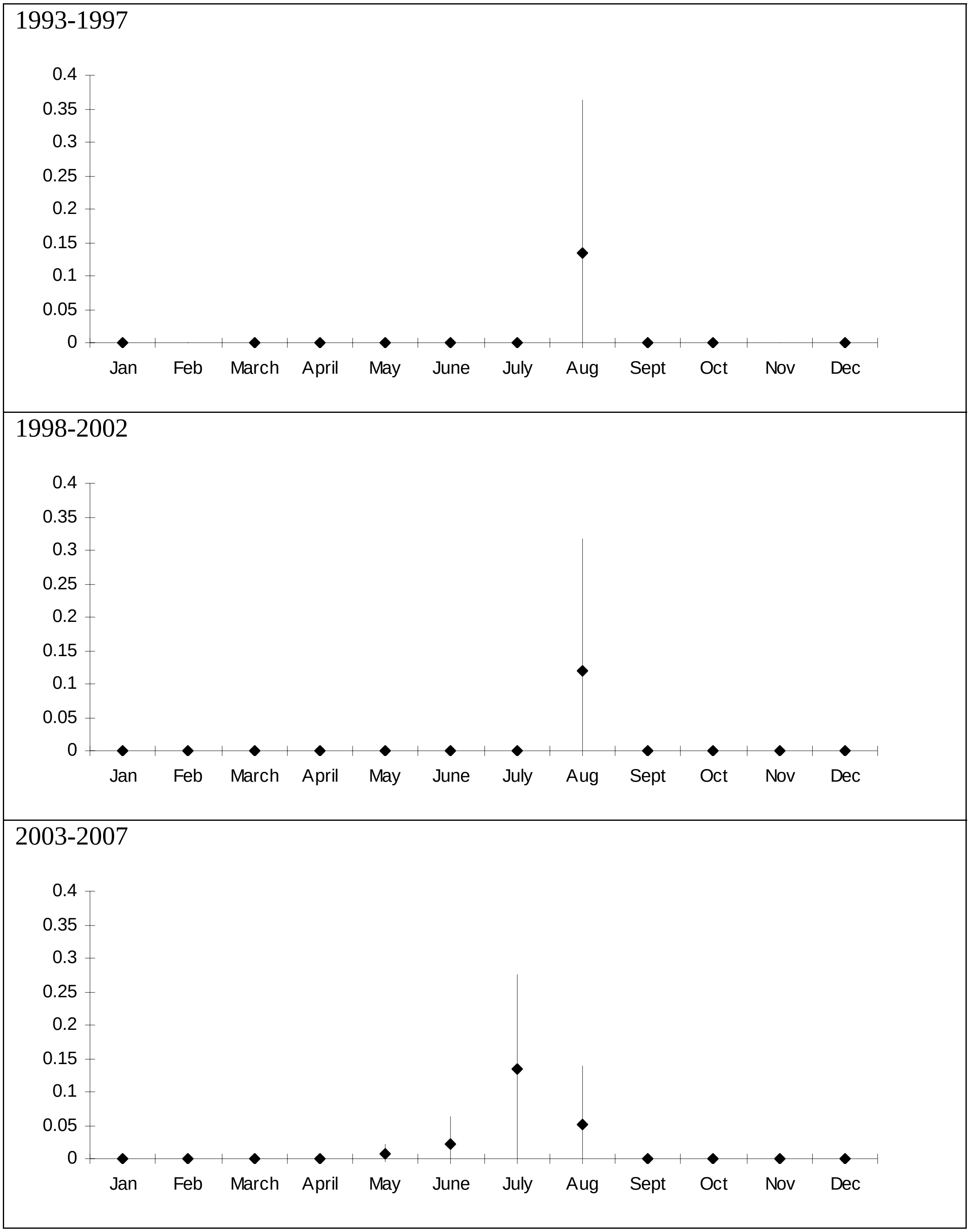


Fig. 11(a). Seasonal Variation in Bottlenose Dolphin Sighting Rates: From Vessel-based Surveys

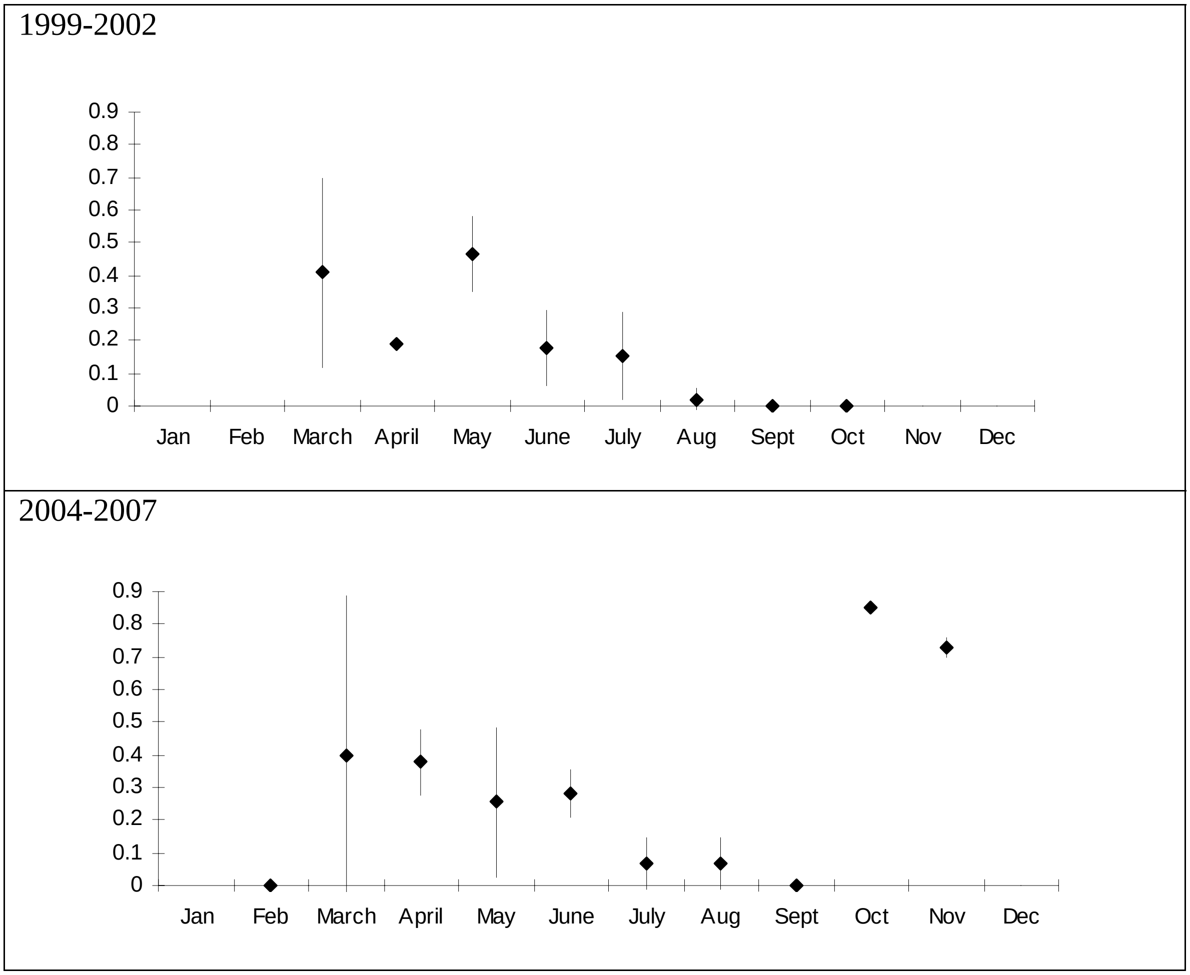


Fig. 11(b). Seasonal Variation in Harbour Porpoise Sighting Rates: From Vessel-based Surveys

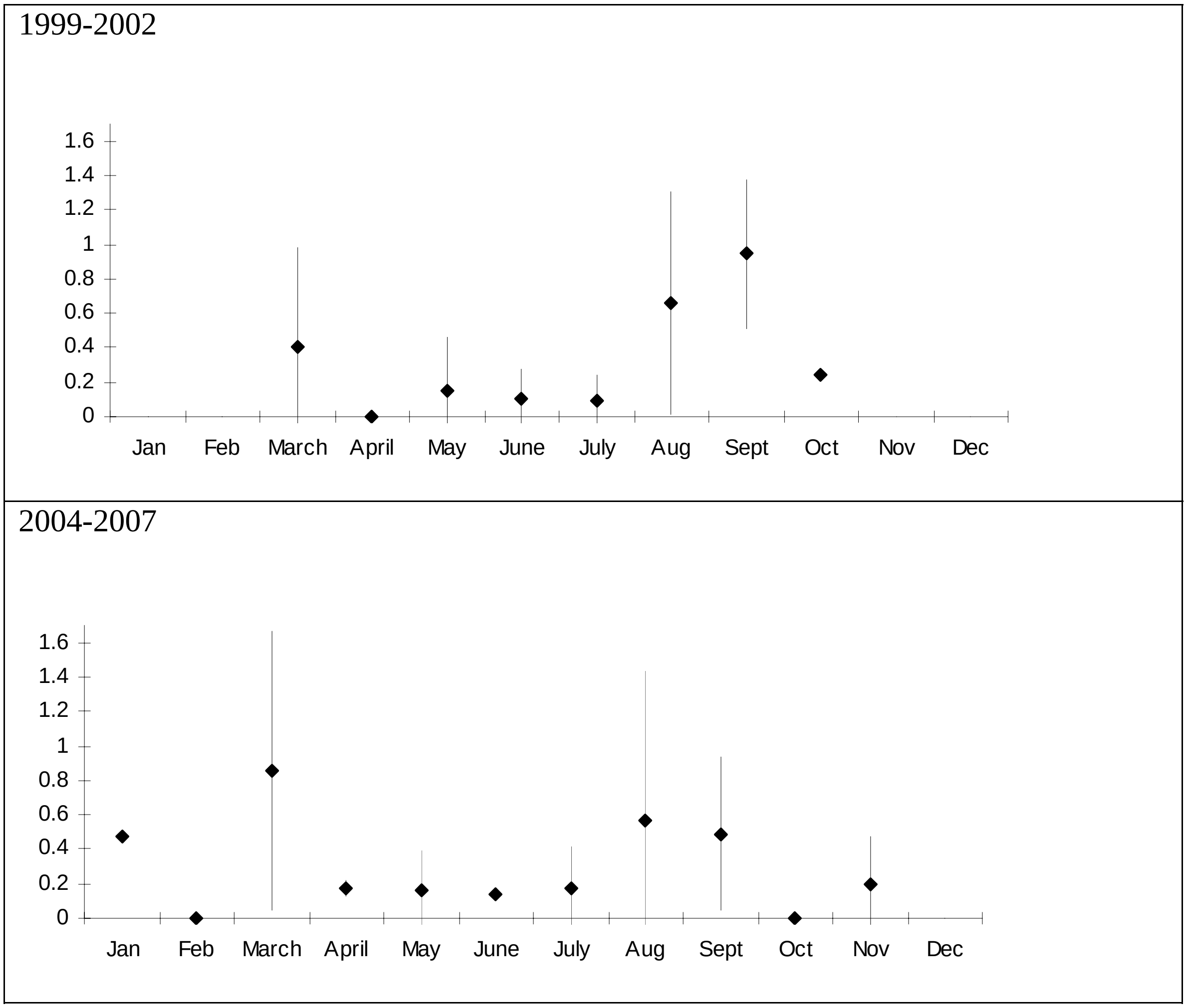


Fig. 11(c). Seasonal Variation in White-beaked Dolphin Sighting Rates: From Vessel-based Surveys

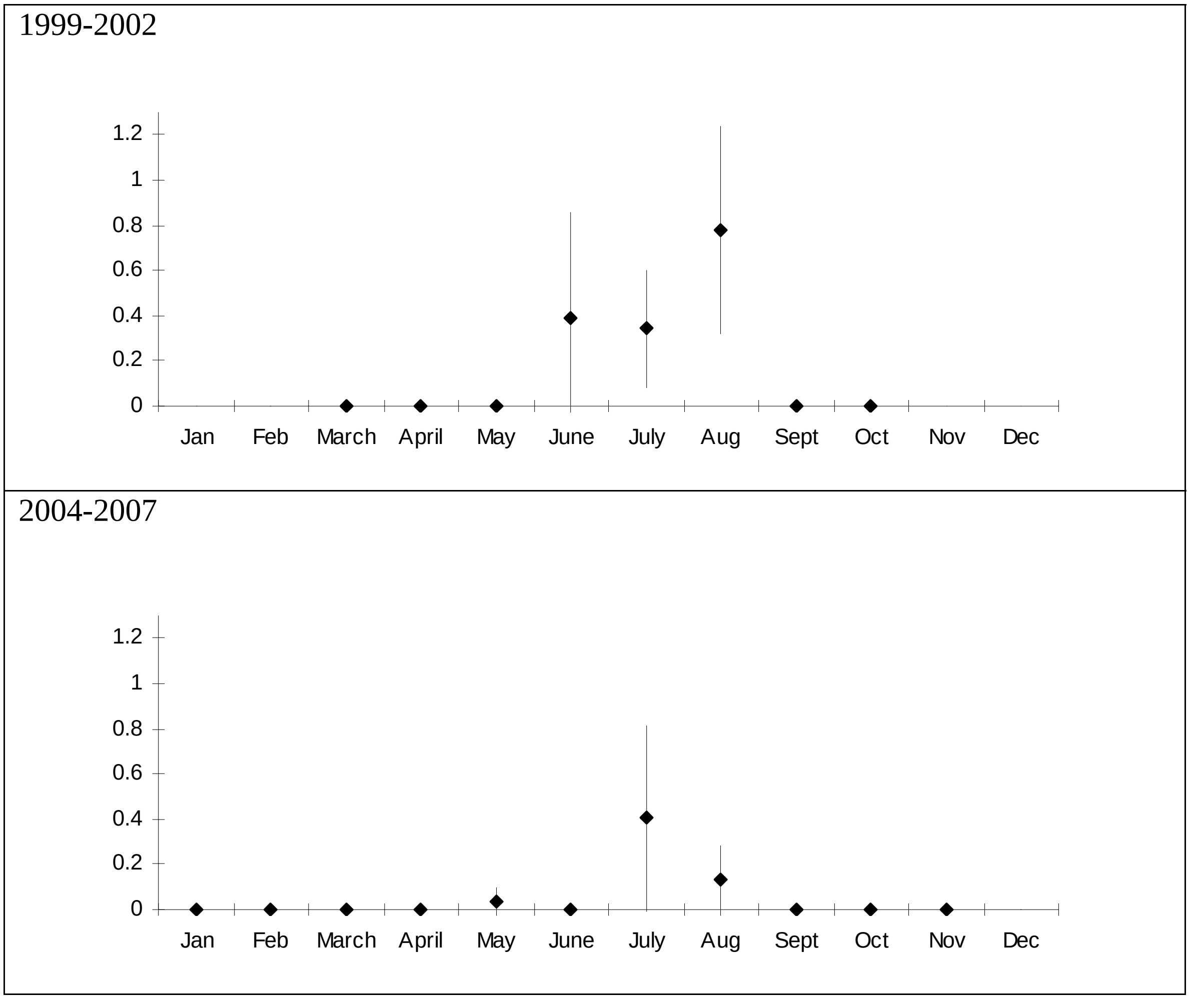


Fig. 11(d). Seasonal Variation in Minke Whale Sighting Rates: From Vessel-based Surveys

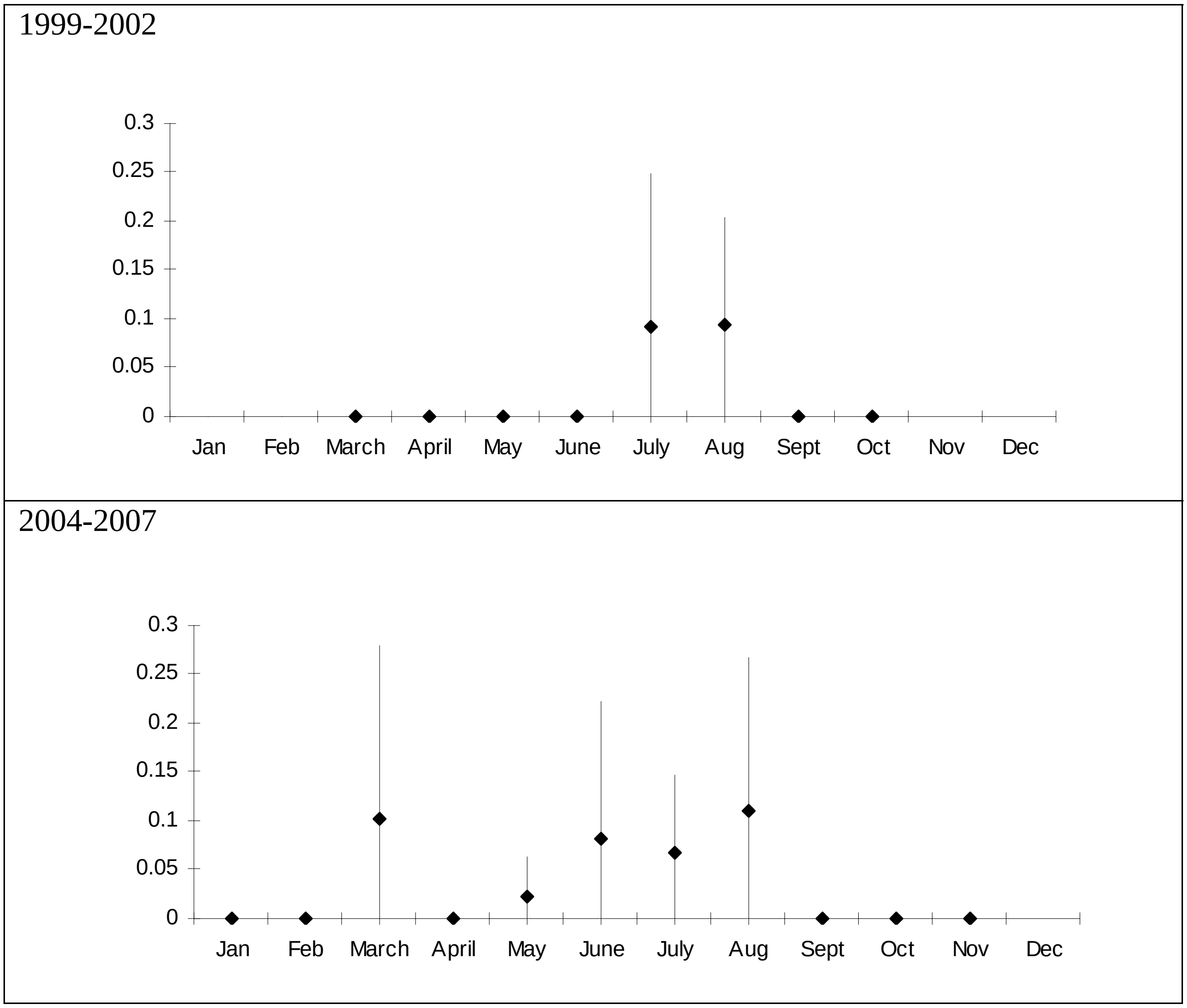


Fig. 12(a). Seasonal Variation in Nos. of Bottlenose Dolphins / hour: From Vessel-based Surveys

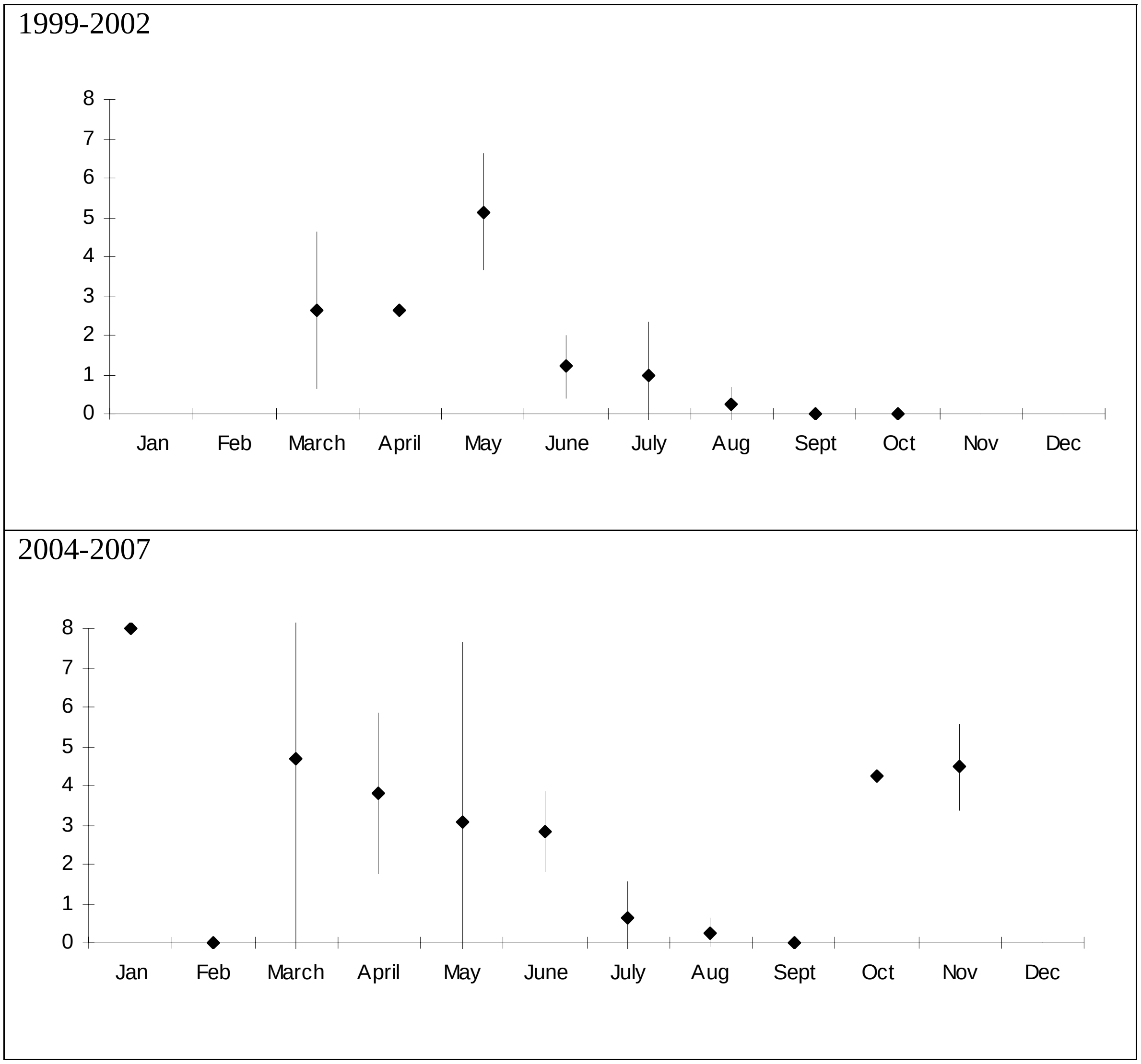


Fig. 12(b). Seasonal Variation in Nos. of Harbour Porpoises/ hour: From Vessel-based Surveys

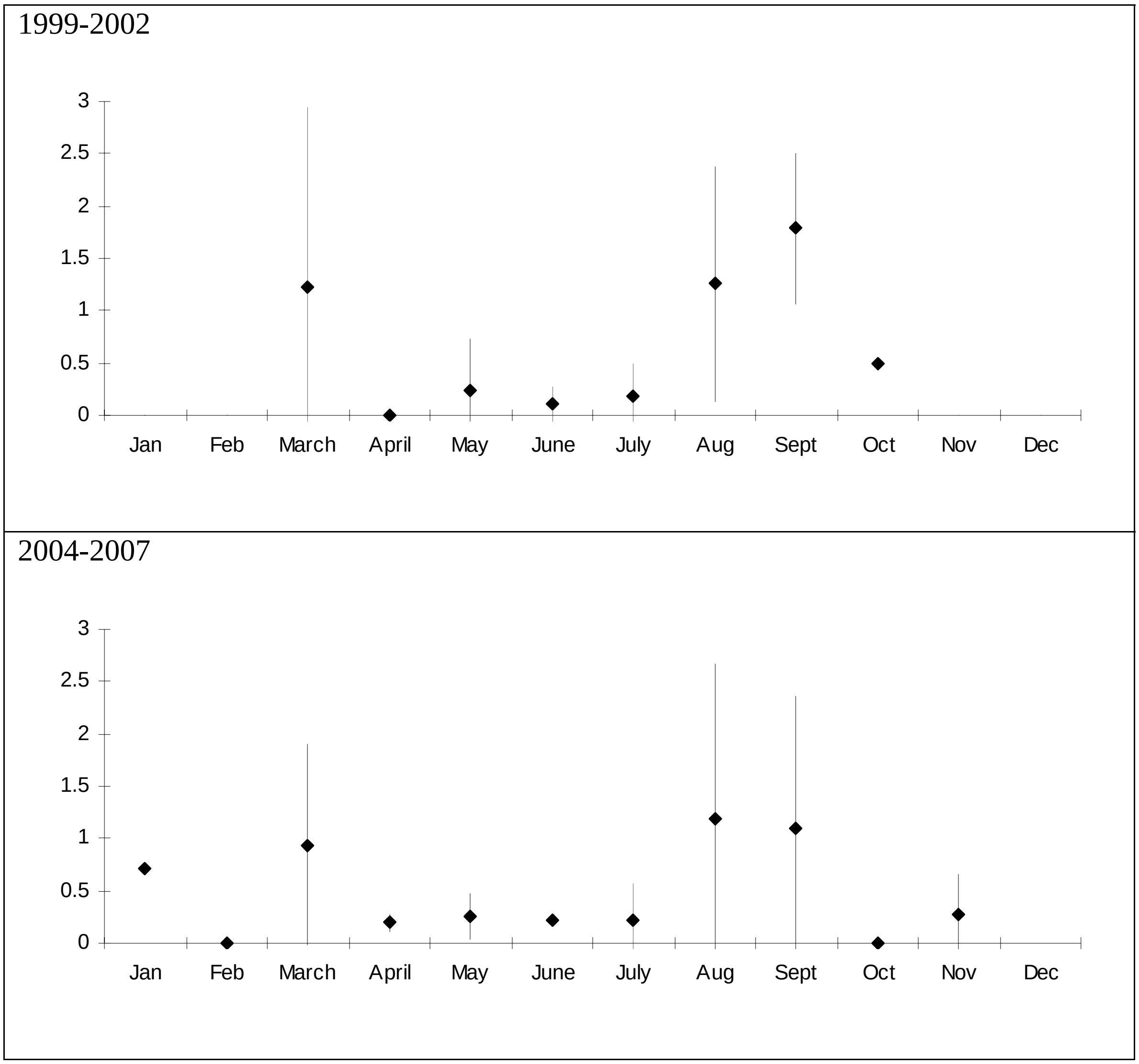


Fig. 12(c). Seasonal Variation in Nos. of White-beaked Dolphins / hour: From Vessel-based Surveys

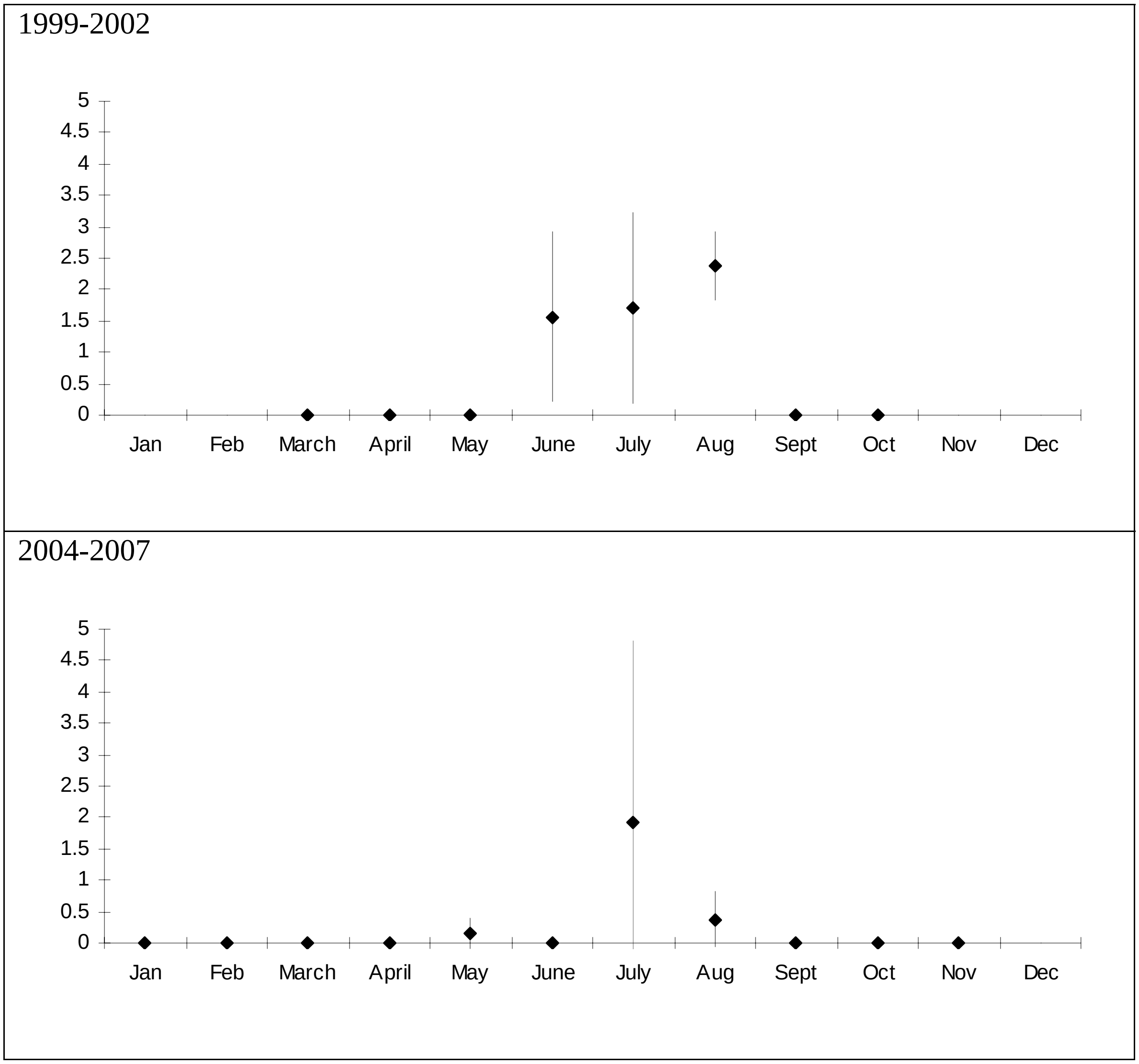


Fig. 12 (d). Seasonal Variation in Nos. of Minke Whales / hour: From Vessel-based Surveys