Marine plastic debris in northern fulmars from the Canadian high Arctic

Mark L. Mallory

Canadian Wildlife Service, P.O. Box 1714, Iqaluit, NU, Canada X0A 0H0

Seabirds are often considered to be effective monitors of the health of marine ecosystems, because they forage over large geographic areas, feed at various trophic levels in the marine food web, and large numbers of birds can be monitored at discrete colonies (Cairns, 1987; Furness and Camphuysen, 1997). While known as bioindicators of marine productivity (Frederiksen et al., 2006), climate change (Thompson and Ollason, 2001), or contaminants (Braune et al., 2005), certain types of seabirds also indicate trends in levels of particulate debris (especially plastic garbage) in the ocean (Furness, 1985; Robards et al., 1995; Van Franeker and Meijboom, 2007). In particular, the Procellariiformes (petrels) appear prone to mistaking pieces of garbage floating on the ocean for prey items (Laist, 1997). These birds ingest the plastic fragments (industrial or user plastic), which can lead to a variety of deleterious health effects (van Franeker, 1985; Ryan, 1987; Burger and Gochfield, 2002). Sampling of marine birds has shown that pollution by plastic debris has increased on our oceans in recent decades (Moser and Lee, 1992; Robards et al., 1995).

The northern fulmar (*Fulmarus glacialis*) is the only petrel found in the Boreal, Low Arctic and High Arctic oceanographic zones of the North Pacific and North Atlantic oceans (Salomonsen, 1965; Hatch and Nettleship, 1998). Plastic debris has been found in the digestive tracts of fulmars across most of its range (van Franeker, 1985; Moser and Lee, 1992; Robards et al., 1995; Mallory et al., 2006a), but there is no published information on plastic in the diet of birds from the Canadian high Arctic. This region supports more than 500,000 fulmars (Gaston et al., 2006), but the area is geographically remote from significant levels of industrial activity, shipping, and most garbage sources, and marine waters are covered by sea ice for approximately half of the year. Nonetheless, fulmars from the Canadian high Arctic spend the winter in the North Atlantic Ocean, and in the spring migrate north through Davis Strait (Mallory et al., 2008), both areas where they could ingest plastic. In this paper I present the first evidence of plastic debris found in breeding fulmars from the Canadian Arctic archipelago. Previous research has shown that the incidence of plastic debris in fulmars is lower for birds collected at higher latitudes (van Franeker, 1985; Robards et al., 1997), and thus I predicted that fulmars in the Canadian high Arctic would have the lowest incidence of plastic debris of any study. Moreover, if fulmars were acquiring most of their plastic during wintering and spring migration instead of on the foraging grounds during breeding (i.e., few sources of garbage in their breeding grounds), then I expected birds collected at their colony early in the breeding season to have (1) more plastic fragments, (2) larger plastic fragments, and (3) more fragments in the proventriculus (the first part of their stomach) than gizzard, compared to fulmars collected later in the season, when plastic fragments would be more digested.

Ecological investigations of fulmars were conducted at the Cape Vera colony (76°15′ N, 89°15′ W; Fig. 1), northern Devon Island, Nunavut, Canada, between 26 May to 22 August 2003 and 14 May to 9 August 2004 (Mallory and Forbes, 2007). I collected 102 adult northern fulmars (2003 – 32 breeders, 39 non-breeders; 2004 – 31 breeders) either by shooting them as they flew near the colony, or using a noose pole to capture birds on the nest and then immediately decapitating them. Carcasses were frozen and shipped to the Long Point Waterfowl and Wetlands Fund Avian Energetics Laboratory. Each carcass was thawed and the contents of the proventriculus and gizzard removed, put in containers, and shipped to Iqaluit, Nunavut. Plastic debris were sorted, dried, measured (±0.1 mm), and weighed (±0.01 g), and the shape of each fragment was recorded (circle, square, rectangle, triangle) for calculations of surface area and volume. Fulmar carcasses were examined in a suite of studies including diet, morphometry (Mallory and Forbes, 2005), haematology (Edwards et al., 2005), contaminants (Mallory et al., 2006b), parasitology (Mallory et al., 2006c), and molt (Allard et al., 2008).

Out of 102 fulmars collected, 32 (31%) had at least one piece of plastic debris in their digestive system, and the average affected fulmar carried 7.4 ± 2.1SE plastic fragments. Collections were temporally biased in relation to breeding status, such that 89% of the 37 fulmars collected in May and June during pre-laying and early incubation were breeders, whereas only 46% of the 65 fulmars collected during July and August in late incubation and early chick-rearing were breeders (Fisher Exact Test, $P < 0.001$). Nonetheless, the proportion of birds containing plastic pieces was statistically similar through the breeding season (Fig. 2a). During May and June, 35% of birds contained plastic, while during July and August, 29% had plastic fragments (Fisher Exact Test, $P = 0.6$). Using only July samples, 6 of 25 breeders contained plastic, while 8 of 28 non-breeders had plastic (Fisher Exact Test, $P = 0.8$). Thus, breeding and non-breeding fulmars had a similar incidence of ingested plastic.

Of the 236 pieces of plastic recovered from the fulmars, 118 (50%) were found in the proventriculus while 118 (50%) were found in the gizzard. However, this pattern varied through the breeding season (Fig. 2b). In May and June, 70% of the plastic pieces were found in the proventriculus of collected birds, whereas in July and August, 94% of the fragments were found in the gizzard (Fisher Exact test, $P < 0.001$).

Plastic fragments were black, blue,[1] brown, gray, red, orange, yellow, beige, or clear, although 59% of the fragments were white (Fig. 3). Only five (2%) of the plastic pieces were industrial plastic beads, with the remainder (98%) user plastic. Twenty-four (10%) of the plastic pieces were soft (rubber-like), while four pieces (up to 11 cm long) appeared to be thread from a fishing line or net. All other fragments were rigid, most of which were from plastic containers. Plastic pieces were generally small (Fig. 4), with a mean length 1.06 ± 0.07 cm, width 0.60 ± 0.03 cm, thickness 0.07 ± 0.002 cm, and volume of 0.04 ± 0.003 cm^3. The mean surface area (one side) of plastic fragments found in fulmars in May or June (0.66 ± 0.07 cm^2) was larger than that of fragments from July and August (0.62 ± 0.07 cm^2; Mann Whitney Test, $U = 4796$, $P = 0.017$), although length, width and volume of fragments did not differ between time periods (all $P > 0.13$). Twenty-eight plastic fragments were heavy enough to weigh (i.e., >0.01 g), with a mean mass of 0.06 ± 0.005 g, and for six fulmars, the mean mass of plastic in their digestive tract was 0.31 ± 0.21 g. The maximum mass of plastic found in any bird was 1.35 g (0.2% of a 700 g adult), and in one fulmar, a maximum count of 54 plastic fragments comprised 2.6 cm^3 of digestive tract volume.

E-mail address: mark.mallory@ec.gc.ca

[1] For interpretation of color in Fig. 3, the reader is referred to the web version of this article.

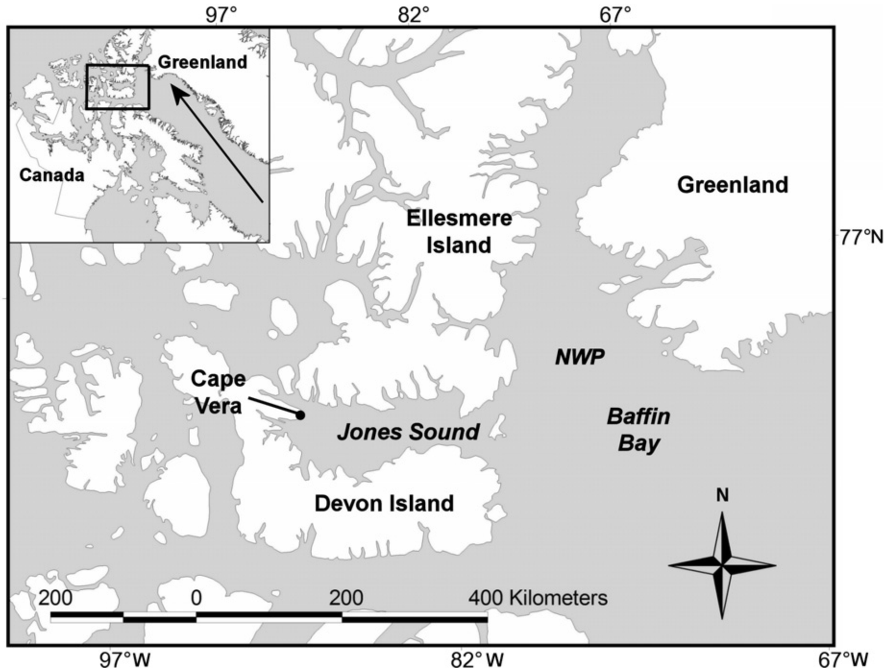

Fig. 1. Northern fulmars were collected at the Cape Vera study, northern Devon Island, Nunavut, Canada. The arrow in the inset shows the direction of spring migration from the wintering area in the North Atlantic Ocean, and "NWP" in the main map refers to the North Water Polynya, a region of open water surrounded by sea ice, in which fulmars from Cape Vera feed for much of the breeding season.

As predicted, the incidence of plastic debris in high Arctic fulmars was low. Thirty-one percent of fulmars at Cape Vera had plastic debris in their digestive tracts, lower than the 79–100% occurrence previously reported in the North Pacific, the North Sea, or the North Atlantic (van Franeker, 1985; Moser and Lee, 1992; Robards et al., 1997; van Franeker and Meijboom, 2007), and similar to the 36% found in Davis Strait, Nunavut (Mallory et al., 2006a). Despite the relatively low incidence of plastic in Arctic fulmars, the proportion still represents an increase in occurrence over the past three decades, as there were no reports of plastic in the diet of fulmars collected in the 1970s in the high Arctic (Bradstreet, 1976). Thus, the Canadian Arctic marine ecosystem has not been immune to the worldwide pattern of increasing pollution from marine plastic debris (Coe and Rogers, 1997).

The incidence of plastic in fulmars was not lower in birds collected later in the season as I had expected, because nearly half of the August birds contained plastic, an increase from the relatively low incidence in July. Hatch (1989) proposed that many non-breeding fulmars arrived at Alaskan colonies in August, that is, later in the breeding season. If fulmars at Cape Vera have a similar colony attendance dynamic, then the proportional increase in August could reflect the recent arrival of birds which had been feeding in areas where the risk of ingesting plastic fragments was higher than at foraging areas closer to Cape Vera. However, at present there are no data to assess this.

Only 2% of the plastic fragments in Cape Vera fulmars were industrial plastic, similar to reports from Davis Strait, Nunavut (Mallory et al., 2006a), whereas this type of debris comprises a large proportion of the debris in fulmars elsewhere (van Franeker, 1985; Robards et al., 1997). The lack of industrial plastic debris in the Arctic was not surprising, because nearby sources of this plastic (manufacturing plants or transport of raw materials) are few in Nunavut, Greenland, or Atlantic Canada, whereas user plastic can blow into the ocean in ports and from communities and garbage dumps, or be carried along on ocean currents (Coe and Rogers, 1997). However, I cannot discount the possibility that small, industrial plastic pellets could have been ingested by these birds during the winter, but were already digested by the time the birds arrived at their colonies (Ryan and Jackson, 1987). Van Franeker and Meijboom (2007) noted that fulmars in the North Sea had ingested an

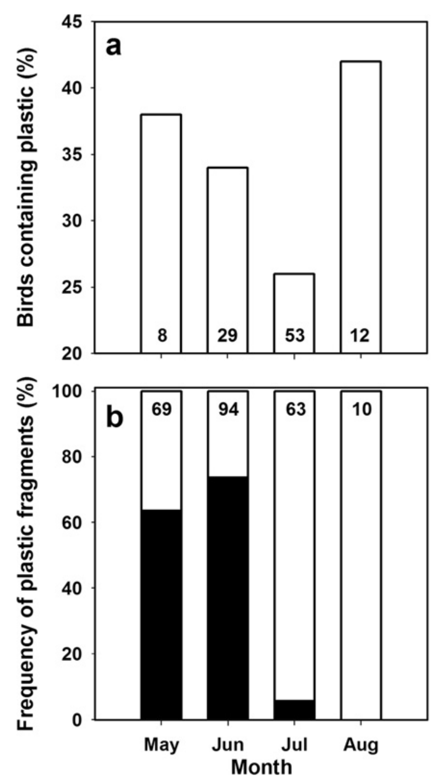

Fig. 2. Temporal distribution in the proportion of: (a) fulmars containing at least one plastic particle in their digestive tract; and (b) plastic fragments found in the proventriculus (black) or gizzard (white) of fulmars. Numbers on bars are sample sizes for that month.

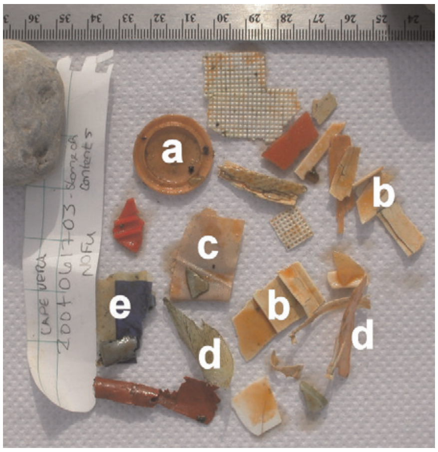

Fig. 3. Plastic fragments from the proventriculus of one fulmar, with identifiable pieces from: (a) bottle cap liner, (b) plastic containers, (c) adhesive bandage, (d) heavy tape, (e) snack food wrapper.

average of 0.33 g of plastic, with over 40 pieces of plastic per bird. I found a similar mass of plastic for those high Arctic birds that carried plastic (0.31 g), but only seven pieces per bird, presumably attributable to a lack of the numerous, small, light industrial plastic pieces found in North Sea birds.

This study was different from most other studies of plastic ingestion by fulmars, in that I was able to sample birds from the same colony through the breeding season. With this protocol, I determined that breeding and non-breeding fulmars had a similar incidence of ingested plastic. Moreover, I found that birds collected early in the season had more plastic in their proventriculus than their gizzard compared to birds collected later in the season, and that there was a tendency for plastic fragments to be larger for earlier collections. This suggests that birds arrived with recently ingested plastic, and that it moved through their digestive system and was broken down (i.e., made smaller) through the season, as found by Ryan and Jackson (1987) for whitechinned petrels (*Procellaria aequinoctialis*). Such a pattern would be consistent with birds acquiring most of their plastic debris during late winter or on migration, and ingesting relatively little during the breeding season. This interpretation is supported by information on the ecology of high Arctic fulmars. Most fulmars at this colony spend the winter in the Labrador Sea between Canada and Greenland (Mallory et al., 2008). After initially returning to their nest sites at the start of May (Mallory and Forbes, 2007), fulmars may leave the high Arctic altogether in late May just prior to egg-laying (McLaren, 1982), presumably to feed in open water off of west Greenland or in Davis Strait. Through much of the breeding season, these fulmars feed in the North Water Polynya up to 500 km from the colony (Mallory et al., 2008), an area of open water between Ellesmere Island and Greenland (Fig. 1) which is blocked from the south by sea ice that persists into July. Implicit in this interpretation is that the north-flowing, West Greenland Current would not move much floating marine debris past the barrier of sea ice and into the polynya, until the ice disintegrates later in the summer.

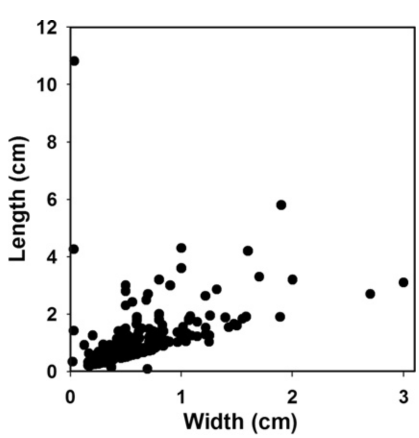

Fig. 4. Distribution of plastic fragment sizes from the digestive tracts of fulmars collected in the Canadian high Arctic.

In recent years, the alteration and degradation of the Canadian Arctic marine environment by various anthropogenic stressors has received much attention (e.g., ACIA, 2005; Braune et al., 2005). However, little monitoring has been directed towards pollution by plastic debris, despite that waste plastic is a worldwide marine pollution problem that affects a wide range of wildlife species (Laist, 1997). Unlike most of the world's oceans, marine waters of the Canadian Arctic remain ice-covered for more than half of the year, and there is only a small, local human population and limited industry to generate local sources of debris. Moreover, marine currents move south and east through the Arctic Archipelago from High Arctic regions (ACIA, 2005) where presumably few pieces of plastic debris would enter the marine environment. Nonetheless, plastic debris appears to be entering the Arctic marine ecosystem through long-range transport on ocean currents, as well as bio-transport in species like fulmars (e.g., Blais et al., 2005). With growing Arctic communities, reductions in sea ice timing and extent, and increases in ship traffic, we should expect that monitoring of fulmar diet will indicate that more, not less, plastic debris is entering marine waters of the Canadian high Arctic in the coming decades. Therefore I recommend that monitoring for plastic debris be added as a component of the existing pollutant monitoring program in the Canadian Arctic (e.g., Braune et al., 2005). Moreover, sampling of fulmars for debris should be conducted early in the breeding season, as this would enhance the opportunity to identify the types and possibly sources of plastic being ingested by Canadian fulmars.

Acknowledgments

My thanks to the field crews at Cape Vera in 2003 and 2004, Kerrie Wilcox and the LPWWRF Avian Energetics Lab for conducting the dissections of the fulmars, Alissa Moenting for assistance in measuring some of the plastic fragments, and Jason Akearok for preparing Fig. 1. Collections were in accordance with Canadian Council on Animal Care guidelines, and were conducted under the following permits: research (NUN-SCI-03-02, WL000190, WL000714), animal care (2003PNR017, 2004PNR021, 2005PNR-021), and land use (59A/7-2-2). Financial support was provided by Environment Canada (CWS and NEI), and Natural Resources Canada (PCSP).

References

ACIA, 2005. Arctic Climate Impact Assessment. Cambridge University Press, Cambridge, UK.

Allard, K.A., Mallory, M.L., Wilcox, K.L., Forbes, M.R., 2008. Prebasic molt initiation and progress in northern fulmars of the high Arctic: do molt and breeding overlap? Polar Biology 31, 181–188.

Blais, J.M., Kimpe, L.E., McMahon, D., Keatley, B.E., Mallory, M.L., Douglas, M.S.V., Smol, J.P., 2005. Arctic seabirds transport marine-derived contaminants. Science 309, 445.

Bradstreet, M.S.W., 1976. Summer Feeding Ecology of Seabirds in Eastern Lancaster Sound. LGL Ltd., Toronto.

Braune, B.M., Outridge, P.M., Fish, A.T., Muir, D.C.G., Helm, P.A., Hobbs, K., Hoekstra, P.F., Kuzyk, Z.A., Kwan, M., Letcher, R.J., Lockhart, W.L., Norstrom, R.J., Stern, G.A., Stirling, I., 2005. Persistent organic pollutants and mercury in marine biota of the Canadian Arctic: an overview of spatial and temporal trends. Science of the Total Environment 351–352, 4–56.

Burger, J., Gochfield, M., 2002. Effects of chemicals and pollution on seabirds. In: Schreiber, E.A., Burger, J. (Eds.), Biology of Marine Birds. CRC Press, New York, pp. 485–525.

Cairns, D.K., 1987. Seabirds as indicators of marine food supplies. Biological Oceanography 5, 261–271.
Coe, J.M., Rogers, D.B., 1997. Marine Debris – Sources, Impacts and Solutions. Springer-Verlag, New York.
Edwards, D.B., Mallory, M.L., Forbes, M.R., 2005. Variation in baseline haematology of northern fulmars (*Fulmarus glacialis*) in the Canadian high arctic. Comparative Clinical Pathology 14, 206–209.
Frederiksen, M., Edwards, M., Richardson, A.J., Halliday, N.C., Wanless, S., 2006. From plankton to top predators: bottom-up control of a marine food web across four trophic levels. Journal of Animal Ecology 75, 1259–1268.
Furness, R.W., 1985. Plastic particle pollution: accumulation by procellariiform seabirds in Scottish colonies. Marine Pollution Bulletin 16, 103–106.
Furness, R.W., Camphuysen, C.J., 1997. Seabirds as monitors of the marine environment. ICES Journal of Marine Science 54, 726–737.
Gaston, A.J., Mallory, M.L., Gilchrist, H.G., O'Donovan, K., 2006. Status, trends and attendance patterns of the Northern Fulmar *Fulmarus glacialis* in Nunavut, Canada. Arctic 59, 165–178.
Hatch, S.A., 1989. Diurnal and seasonal patterns of colony attendance in the northern fulmar, *Fulmarus glacialis*, in Alaska. Canadian Field-Naturalist 103, 248–260.
Hatch, S.A., Nettleship, D.N., 1998. Northern Fulmar (*Fulmarus glacialis*). In: Poole, A., Gill, F. (Eds.), The Birds of North America, No. 361. The Birds of North America Inc., Philadelphia, PA.
Laist, D.W., 1997. Impacts of marine debris: entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records. In: Coe, J.M., Rogers, D.B. (Eds.), Marine debris – Sources, Impacts and Solutions. Springer-Verlag, New York, pp. 99–143.
Mallory, M.L., Forbes, M.R., 2005. Sex discrimination and measurement bias in northern fulmars (*Fulmarus glacialis*) from the Canadian arctic. Ardea 93, 25–36.
Mallory, M.L., Forbes, M.R., 2007. Does sea-ice cover constrain the breeding schedules of high arctic northern fulmars? Condor 109, 894–906.
Mallory, M.L., Robertson, G.J., Moenting, A., 2006a. Marine plastic debris from northern fulmars in Davis Strait, Nunavut, Canada. Marine Pollution Bulletin 52, 813–815.
Mallory, M.L., Braune, B.M., Forbes, M.R., 2006b. Breeding and contaminant concentrations in northern fulmars (*Fulmarus glacialis* L.) from the Canadian high arctic. Chemosphere 64, 1541–1544.
Mallory, M.L., Forbes, M.R., Galloway, T.D., 2006c. Ectoparasites of northern fulmars *Fulmarus glacialis* (Procellariformes: Procellariidae) from the Canadian Arctic. Polar Biology 29, 353–357.
Mallory, M.L., Akearok, J.A., Edwards, D.B., O'Donovan, K., Gilbert, C.D., 2008. Autumn migration and wintering of northern fulmars (*Fulmarus glacialis*) from the Canadian high Arctic. Polar Biology 31, 745–750.
McLaren, P.L., 1982. Spring migration and habitat use by seabirds in eastern Lancaster Sound and western Baffin Bay. Arctic 35, 88–111.
Moser, M.L., Lee, D.S., 1992. A fourteen-year survey of plastic ingestion by western North Atlantic seabirds. Colonial Waterbirds 15, 83–94.
Robards, M.D., Piatt, J.F., Wohl, K.D., 1995. Increasing frequency of plastic particles ingested by seabirds in the subarctic North Pacific. Marine Pollution Bulletin 30, 151–157.
Robards, M.D., Gould, P.J., Piatt, J.F., 1997. The highest global concentrations and increased abundance of oceanic plastic debris in the North Pacific: evidence from seabirds. In: Coe, J.M., Rogers, D.B. (Eds.), Marine debris – Sources, Impacts and Solutions. Springer-Verlag, New York, pp. 71–80.
Ryan, P.G., 1987. The effects of ingested plastic on seabirds: correlations between plastic load and body condition. Environmental Pollution 46, 119–125.
Ryan, P.G., Jackson, S., 1987. The lifespan of ingested plastic particles in seabirds and their effect on digestive efficiency. Marine Pollution Bulletin 18, 217–219.
Salomonsen, F., 1965. The geographical variation of the fulmar (*Fulmarus glacialis*) and the zones of marine environment in the North Atlantic. Auk 82, 327–355.
Thompson, P.M., Ollason, J.C., 2001. Lagged effects of ocean climate change on fulmar population dynamics. Nature 413, 417–420.
Van Franeker, J.A., 1985. Plastic ingestion in the North Atlantic fulmar. Marine Pollution Bulletin 16, 367–369.
Van Franeker, J.A., Meijboom, A., 2007. Fulmar litter EcoQO monitoring in the Netherlands 1982–2005 in relation to EU Directive 2000/59/EC on port reception facilities. IMARES Texel report C019/07, Wageningen.

doi:10.1016/j.marpolbul.2008.04.017

Presence and origin of polycyclic aromatic hydrocarbon in sediments of nine coastal lagoons in central Vietnam

Silvia Giuliani [a,*], Mario Sprovieri [b], Mauro Frignani [a], Nguyen Huu Cu [c], Cristian Mugnai [a], Luca Giorgio Bellucci [a], Sonia Albertazzi [a], Stefania Romano [a], Maria Luisa Feo [b], Ennio Marsella [b], Dang Hoai Nhon [c]

[a] *CNR-ISMAR, Consiglio Nazionale delle Ricerche, Istituto di Scienze Marine, Sede di Bologna, Via Gobetti 101, 40129 Bologna, Italy*
[b] *CNR-IAMC, Calata di Porta di Massa, Naples, Italy*
[c] *IMER, 246 Da Nang Street, Haiphong City, Viet Nam*

Several natural and anthropogenic processes can lead to the formation of polycyclic aromatic hydrocarbons (PAHs), a well known class of compounds, many of which with mutagenic and carcinogenic properties (Nielsen et al., 1995), that are regarded as priority pollutants by the US Environmental Protection Agency (US EPA, 1993). Anthropogenic sources include combustion of fossil fuels, coal gasification and liquification processes, petroleum cracking, waste incineration and production of: coke, carbon black, coal tar pitch and asphalt, (McCready et al., 2000). Another common anthropogenic source of PAHs is spillage of fossil fuels, both unrefined and refined products. PAHs also stem from natural combustion sources such as forest fires, and certain compounds (perylene and retene) are thought to be diagenetically produced (Wakeham et al., 1980).

Because of their hydrophobic nature, PAHs in the aquatic environment are easily adsorbed onto settling particles and finally accumulate in sediments. This adsorption-settling process is continuous over time, therefore sediments can act as recorders of contaminant inputs as well as of general environmental change over time (Kannan et al., 2005). It follows that the study of sediment records can provide information on levels, history and trends of pollutants in aquatic environments. Moreover, under particular erosive and resuspending conditions, sediments can represent a source for toxic substances in aquatic environments and may affect wildlife and humans via the food chain.

In Vietnam, information on pollutant sources and distribution is very poor, despite the strong impact on the environment that may have been caused by both the Indochinese Wars and related events (1945–1975) as well as the recent economic development. Therefore, the major objective of the current study was to assess history of PAH contamination, relative importance of the sources, present trends, and potential toxicological significance in central Vietnam lagoons. These areas are valuable and diverse ecosystems, important tourist attractions and sites for fishing and aquaculture activities, and therefore represent key environments for the sustainable development of the Vietnamese economy.

The nine lagoons (Fig. 1) are situated in central Vietnam between 11°N and 16°N in the provinces of Thua Thien-Hue, Da Nang, Quang Nam, Quang Ngai, Binh Dinh, Phu Yen, Khanh Hoa and Ninh

* Corresponding author. Tel.: +39 051 6398864; fax: +39 051 6398940.
E-mail address: silvia.giuliani@bo.ismar.cnr.it (S. Giuliani).