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Overland Flights of Terns and Consequent High Exposure to Polychlorinated Biphenyls (PCBs) in Northwest France in the 1970s

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Abstract.—Sandwich (*Thalasseus sandvicensis*), Common (*Sterna hirundo*) and Roseate Terns (*S. dougallii*) made overland flights from a breeding site in Brittany (northwest France) to forage in a semi-enclosed basin (Rade de Brest) ~30 km away in 1976 and 1978. The foraging area was contaminated with polychlorinated biphenyls (PCBs) and high levels of PCBs were detected in several tern eggs. Levels of PCBs in tern eggs were sufficiently high to have caused adverse effects on reproduction. PCBs should be considered as potential contributory causes of declines in tern populations in the 1960s–1970s, in addition to other known causes including predation and trapping in the winter quarters.

Key words.—Brittany, overland flights, PCBs, terns, toxic effects

During studies of Roseate Terns (*Sterna dougallii*) in northwest Europe (Cabot 1996), we visited many tern colonies in France in the 1970s. In 1976 and 1978, we visited the Îlots de Trevoc'h and observed terns of several species — Sandwich (*Thalasseus sandvicensis*), Roseate, and Common (*S. hirundo*) Terns — flying overland to forage in the Rade de Brest, a semi-enclosed arm of the sea ~30 km away. The Rade de Brest was subsequently found to be contaminated with polychlorinated biphenyls (PCBs); several tern eggs that we collected at Trevoc'h proved to have high concentrations of PCBs. Here, we report our observations of overland flights, summarize information on PCB contamination in the Rade de Brest and in tern eggs, and assess whether PCBs might have contributed to declines in tern populations in the 1970s.

METHODS

Study Sites and Field Methods

The Îlots de Trevoc'h (48.587°N, 4.641°W) are a group of about 10 small islands in the Aber Benoît in northern Finistère (Fig. 1; Jonin 2014). We visited the islands on 24–25 and 30 June 1976 and 25–27 July 1978; we counted terns nesting there and in 1978 we collected several abandoned eggs of Sandwich and Common Terns for contaminant analysis. On 25 June–7 July 1976 and 25–27 July 1978, we observed Sandwich, Common and Roseate Terns foraging in the waters around Trevoc'h and in the Rade de Brest 30 km to the south (Fig. 1).

Laboratory Procedures

Contents of eggs collected in 1978 were analyzed for PCBs and other organochlorine contaminants by C.H. Walker at the University of Reading (UK); results were reported by Walker

(1979) and Walker and Johnston (1989). Walker (1979) used 'state-of-the-art' methods of the time, including extraction and clean-up by methods used in the Laboratory of the Government Chemist (UK), separation of components by gas-liquid chromatography (GLC) on two columns (SE52 and Apiezon-L), and identification of components by matching to a reference sample of Aroclor® 1254 on both columns. Quantitation was based on the Webb-McCall method (Webb and McCall 1972), in which areas of the main peaks on the chromatograms were compared between the environmental and reference samples. However, Walker (1979) used low-resolution packed columns for GLC, so that concentrations of total PCBs estimated by those methods were recognized to be approximations (Hammond *et al*. 1972, Walker 1979).

Exposure and Risk Assessment

We reviewed data on concentrations of PCBs and other persistent contaminants in environmental samples from northwestern France, including the Rade de Brest, in the 1970s–2000s. We use these data to interpret data on PCBs and other contaminants in terns at Trevoc'h in those years and to identify likely sources of contaminants in the Trevoc'h terns. We use data on the relationships of PCB levels in tern eggs to reproductive success at other sites to estimate risks to terns at Trevoc'h in 1978.

RESULTS

In 1976, we estimated that 500 pairs of Sandwich Terns, 45 pairs of Roseate Terns and 90 pairs of Common Terns nested at Trevoc'h. Numbers nesting there in 1978 were estimated as 580, 79 and 130 pairs, respectively (Jonin 2014).

Overland Flights

On 25 June–6 July 1976, we observed Sandwich and Common Terns foraging in the Aber Benoît and carrying fish towards Trevoc'h. On 7 July 1976 we also observed Sandwich Terns flying southwards overland towards the Rade de Brest (Fig. 1). Later on 7 July 1976, we observed Sandwich, Common and Roseate Terns foraging in the Rade de Brest, especially in the Anse de Kerhuon, and we observed Roseate and Common Terns departing northwards overland and carrying fish towards Trevoc'h (Fig. 1; Cabot and Nisbet 2013). On 25–27 July 1978, we did not see terns foraging in the Aber Benoît, but we saw Sandwich and Roseate Terns flying southwards overland from Trevoc'h towards the Rade de Brest (Fig. 1). Jean-Yves Monnat (pers. comm., May 2021) reported that he frequently observed overland movements of terns from Trevoc'h to and from the Rade de Brest in 1965–1973, although he did not keep detailed notes.

Contaminant levels in tern eggs

Walker (1979) and Walker and Johnston (1989) reported a concentration of 160 mg kg^{-1} PCBs (wet weight of egg contents, hereafter ppm) in a single Sandwich Tern egg, and 50 ppm PCBs in a pooled sample of Sandwich and Common Tern eggs from Trevoc'h in 1978. Numbers of eggs in the pooled sample were not stated but were probably in the range 1–3 of each species (Walker 1979).

Contaminant levels in the Rade de Brest

The Rade de Brest is a deepwater inlet and parts of its shoreline are industrialized, especially around the city and port of Brest and the naval base at Arsenal de Brest (Fig. 1). Marchand *et al*.

(1983) reported measurements of PCB concentrations in seawater, sediments, polychaetes (*Arenicola marina* and *Cirriformia tentaculata*) and mussels (*Mytilus edulis*) at many stations within the Rade de Brest in 1977–1978. Highest concentrations of PCBs in sediments (180–2,100 ng g^{-1}, dry weight, hereafter ppb; Tableau 6 in Marchand *et al*. 1983) were at five stations along the shore from the port of Brest to the L'Elorn estuary (Fig. 1). Concentrations of PCBs in mussels were in the range 200–500 ppb throughout the Rade de Brest but were much higher (1,200–4,200 ppb) at station M2 within Arsenal de Brest (Tableau 10 in Marchand *et al*. 1983). Concentrations of PCBs in polychaetes were in the range 150–750 ppb throughout the Rade de Brest but were much higher at station P3 within the port of Brest (4,480 ppb) and at station P4 to the east (32,400 ppb; Tableau 13 in Marchand *et al*. 1983). Thus, the Rade de Brest was broadly contaminated with PCBs in the 1970s, with highest concentrations along the north shore, including the city and port of Brest, Arsenal de Brest and locations from whence we observed terns carrying fish towards Trevoc'h (Fig. 1).

Since 1979, IFREMER (l'Institut Français de Recherche pour l'Exploitation de la Mer) has surveyed contaminants along the west and north coasts of France, using mussels and Pacific oysters (*Crassostrea gigas*) as sentinel organisms. However, PCBs were not monitored systematically until after 1992. Chiffoleau (2017, Fig. 42) reported a decline by ~80% in concentrations of PCB153 in oysters from the Rade de Brest between 1992 and 2015. In 2012–2015, the highest concentrations of PCB153 and PCB118 (two major components of environmental mixtures of PCBs) in oysters were found at one site in the Rade de Brest, with high levels also at two adjacent sites (Chiffoleau 2017, Fig. 44). The highest levels of (tributyl)tin (TBT) and its metabolites in oysters were found at the same sites (Chiffoleau 2017, Fig. 52).

DISCUSSION

Overland flights

Our observations in 1976 and 1978 indicated that many terns of three species made overland flights of ~30 km from Trevoc'h to foraging areas in the Rade de Brest (Fig. 1). This suggests that the Rade de Brest was a significant foraging area for at least some of the terns nesting at Trevoc'h. The overland crossing of ~30 km is unusual for marine terns, although comparable overland crossings (20–30 km) have been described for Sandwich, Common and Roseate Terns in Ireland and the USA, and even longer overland flights for Caspian Terns (*Hydroprogne caspia*) in the USA (Cabot and Nisbet 2013).

Exposure of terns to PCBs

This is not a formal ecotoxicological study, because our data on exposure of terns to PCBs in the 1970s are limited to two reports (Walker 1979; Walker and Johnston 1989) which did not include the detailed information on sampling, analytical methods and QA/QC procedures that are currently expected. Nevertheless, the reported concentrations of PCBs in tern eggs from Trevoc'h in 1978 (160 and 50 ppm: see RESULTS) are amongst the highest ever reported in piscivorous birds (Hammond *et al*. 1972; Walker and Livingstone 1992). For example, the highest concentrations of PCBs in tern eggs from a site close to the 'hot spot' for PCB contamination in New Bedford Harbor, USA, were ~29 ppm for Common Terns and ~8 ppm for Roseate Terns (Nacci *et al*. 2016). We recognize considerable uncertainties in estimates of concentrations of 'total PCBs' in samples from the 1970s (e.g., Hammond et al. 1972). However, Walker's laboratory was one of the best for

measuring PCB levels in the 1970s and we judge that Walker's estimates for PCBs in tern eggs from Trevoc'h should have been accurate to within (at worst) a factor of 2.

Marchand *et al*. (1983) showed that the northern part of the Rade de Brest, specifically the port of Brest and Arsenal de Brest, were highly contaminated with PCBs in the 1970s (see RESULTS and Fig. 1). Our data show that some terns from Trevoc'h foraged in this area in 1976–1978 (Fig. 1). The association between high levels of PCBs and high levels of TBT (see Chiffoleau 2017 and RESULTS) points to ships as a possible source. The most likely source is Arsenal de Brest: PCBs were used in hydraulic fluids on ships until at least the early 1970s (Nisbet and Sarofim 1972) and TBT was used in anti-fouling paints on large ships until after 1982 (Santillo *et al*. 2001)

Risk Assessment

The most important toxic effects of PCBs on birds (those that occur at the lowest exposure levels) are embryotoxicity and teratogenicity (Barron *et al*. 1995). Most of these effects are caused by a few highly toxic components ('dioxin-like' PCB congeners) that are much more potent than the components that comprise the bulk of the mixtures (Van den Berg *et al.* 1998). The 'dioxin-like' congeners typically comprise only 0.2%–0.5% of the total PCB residues in piscivorous birds (e.g., Nacci *et al*. 2016); they are rarely measured in routine monitoring programs. Hence, risk assessment is usually based on total PCB concentrations, recognizing that these are surrogates for the highly toxic agents within the mixtures.

Assessment of effects of PCBs on piscivorous birds is further complicated by the co-occurrence of DDE [1,1-dichloro-2,2-*bis*(*p*-chlorophenyl)ethylene]; DDE and PCBs are typically correlated in wildlife samples (Hammond *et al*. 1972), so that it is difficult to separate their effects statistically. DDE is embryotoxic and has other effects on reproduction in birds; in

several cases where critical analysis was possible DDE was shown to be more important than PCBs (Nisbet and Fox 2009; and references therein). However, eggs of the Trevoc'h terns contained only 0.2–0.4 ppm DDE (Walker and Johnston 1989), well below the lowest levels associated with adverse effects (Nisbet and Fox 2009), and DDE levels in sediments and biota in the Rade de Brest in 1977–1978 were low compared to PCBs (Marchand *et al*. 1983).

In 3 field studies of Common Terns, mean concentrations of total PCBs in the range 11–13 ppm were associated with measurable adverse effects (hatching failure and/or congenital abnormalities) while concentrations of DDE were low or statistically controlled (Hoffman *et al*. 1993; Becker *et al*. 1993; Ward *et al*. 2010). Estimated concentrations of PCBs in the Trevoc'h terns (50–160 ppm) were much higher than this range, so that substantial adverse effects on hatching success would be expected despite the range of uncertainty in the estimates.

We have found no data on reproductive success of terns at Trevoc'h or elsewhere in Brittany during the 1960s or 1970s. Numbers of Roseate Terns reached peaks of 600–700 pairs at Trevoc'h in 1967 (Jonin 2014) and 3,300 pairs in Britain and Ireland in 1968 (Cabot and Nisbet 2013) but declined precipitously in the later 1960s and 1970s (Cabot and Nisbet 2013); no terns nested at Trevoc'h after 1992 (Jonin 2014). Numbers of Common Terns similarly declined in the 1970s, but those of Sandwich Terns peaked in 1981 and declined thereafter (Capoulade *et al.* 2008; Jonin 2014). These declines have been attributed to trapping by humans in wintering areas (Cabot and Nisbet 2013) and to displacement by gulls (*Larus* spp.) or to predation by birds or mammals at breeding sites (Capoulade *et al*. 2008; Jonin 2014).

Our study suggests that PCBs may have contributed to the population declines in the 1960s–1970s, in addition to factors that were previously identified such as predation,

encroachment by gulls, and trapping in the winter quarters (e.g., Capoulade *et al*. 2008; Cabot and Nisbet 2013; Jonin 2014).

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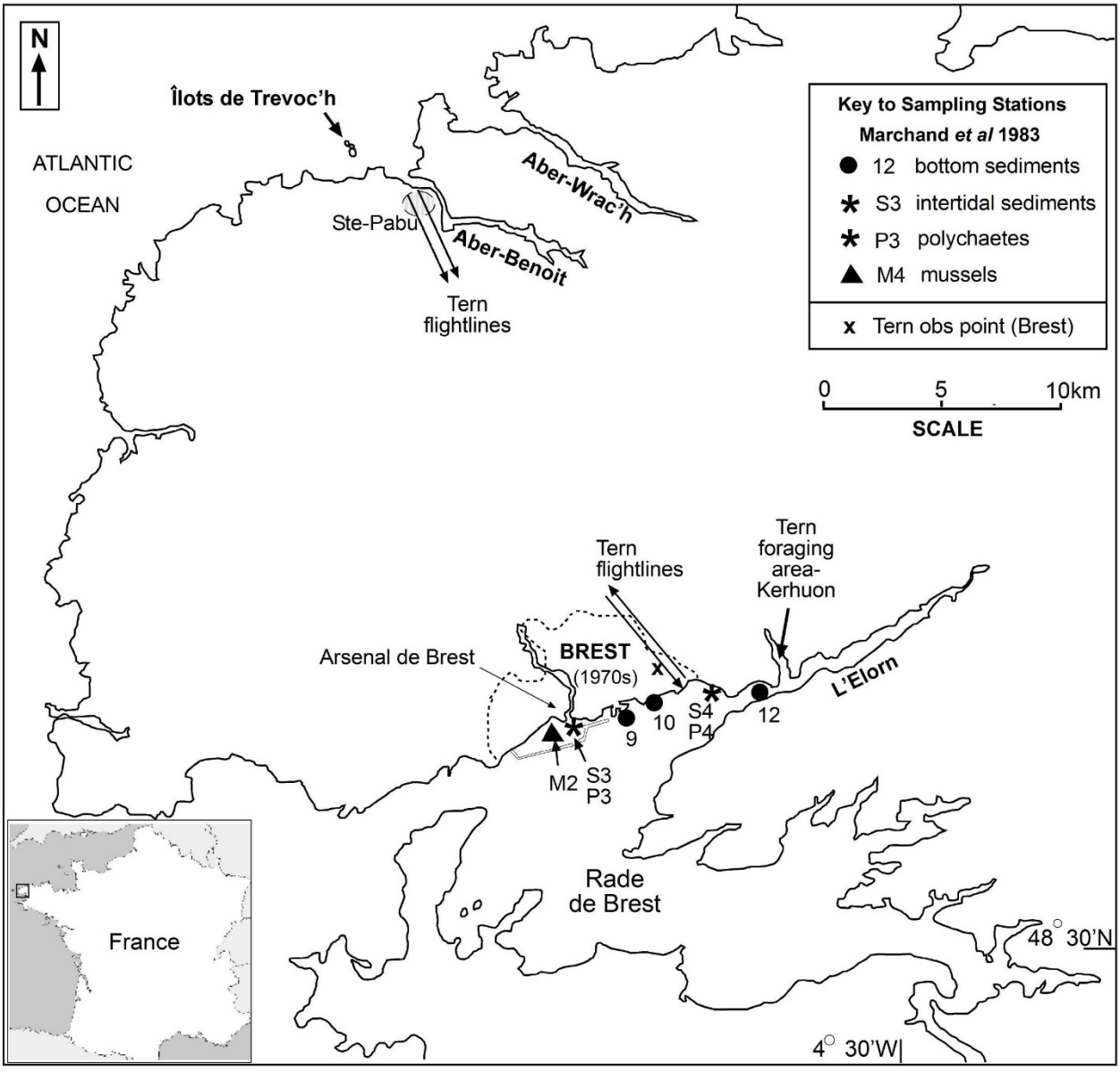
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Figure 1. Map of northwestern Brittany, showing the tern colony at Trevoc'h in relation to the Rade de Brest. Stations where the highest levels of PCBs were found in sediments, mussels and polychaetes in 1977–1978 (Marchand *et al*. 1983) are marked with symbols and numbered corresponding to tables in that paper. Long arrows mark locations where Roseate, Common and/or Sandwich Terns were observed starting overland crossings in 1976 and 1978. The inset shows the location of the study-area in northwest France.

254 Figure 1



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