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TRIBUTYLTIN CONTAMINATION IN THE FIRTH OF FORTH (1975–87)

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ABSTRACT

Contamination of the Firth of Forth (Scotland) by tributyltin compounds leached from antifouling paints has been identified using the degree of penis development (imposex) in the common dogwhelk *Nucella lapillus*. In 1987, a high degree of imposex was observed in the vicinity of pleasure craft activity, fishing harbours and a boat yard, reflecting localised inputs of tributyltin from these sources.

Dogwhelks collected in 1975 from sites comparable to those surveyed in 1987 showed lower degrees of imposex and also a lower incidence of penis development in females.

INTRODUCTION

Methods to assess the degree of contamination of coastal waters by tributyltin (TBT) have included seawater analysis (Cleary and Stebbing, 1985; Balls, 1987; Waldock et al., 1987), and the use of bioindicator organisms having characteristic responses. In this latter category shell thickening in the Pacific oyster, *Crassostrea gigas* (Waldock and Thain, 1983), and the development of a penis and other male characteristics by females (imposex) (Smith, 1981) in the common dogwhelk, *Nucella lapillus* (Gibbs et al., 1987), have been used.

The examination of imposex in dogwhelks is rapid and straightforward, and has proved to be the most sensitive indicator of TBT contamination. Gradients in contamination have been demonstrated in estuaries, open coastal areas and sea lochs subjected to TBT inputs (Bryan et al., 1986; Davies et al., 1987).

A low degree of imposex in dogwhelks was first reported in Britain in 1969 (Blaber, 1970). No further studies were published until the work of Bryan et al. (1986) in southern England, by which time many of the samples they examined showed a high degree of imposex. The development of a penis and vas deferens

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in female dogwhelks may result from long- or short-term exposure to TBT compounds (Bryan et al., 1987). There is no evidence that these characteristics regress if the source of TBT contamination is removed, and thus Bryan et al. (1986) could provide little information as to when the adult dogwhelks they examined were first affected. The link between TBT and imposex was established largely through laboratory experiments (Bryan et al., 1986), because of the difficulty in determining the previous exposure of dogwhelks in the field to TBT. This was supported by field observations of the distribution of affected populations in relation to sources of TBT, and a knowledge of the history of TBT usage.

Copper-based antifouling paints boosted by low concentrations (1%) of TBT compounds were available in the mid-1960s, and were widely used on both yachts and commercial vessels. In 1969/70, two leading paint manufacturers introduced yacht antifoulants which relied solely on high concentrations of TBT ($\sim$12%) as the toxic component. These "free-association" paints rapidly gained in popularity, and by 1972 accounted for 80–90% of the yacht market. Such paints were largely replaced in the 1980s by co-polymer paints which contained rather less TBT ($\sim$5–7%), but were found to be as effective and longer lasting than earlier types.

The Firth of Forth on the east coast of Scotland is a centre for commercial and recreational boating activity. In this report, imposex in current (1987) populations of dogwhelks is used to identify the main sources of TBT in the area, and comparisons are made with the development of imposex in dogwhelks collected in 1975.

MATERIALS AND METHODS

Samples of 40 adult dogwhelks (as identified by Crothers, 1985) were collected during 1987 from 37 sites in the Firth of Forth (Fig. 1). For each animal the shell length was measured and the sex determined by the presence or absence of a sperm-ingesting gland and the appearance of the gonad (Gibbs et al., 1987). The length of the penis (where present) was measured using the eye-piece graticule of a binocular microscope. The degree of imposex (volume of the female penis as a percentage of that of the male penis) was calculated following Gibbs et al. (1987).

Archived samples of 20 adult dogwhelks [collected from six sites (Fig. 1) in 1975 and preserved in alcohol] were made available by the Royal Scottish Museum, Edinburgh, and were examined as above.

RESULTS

The extent of the 1987 survey was limited to areas east of Queensferry by the absence of dogwhelks further west, where suitable substrates are rare, and the salinity is reduced. Some degree of penis development was shown by all but one of the females examined, and, in more severely affected populations, females were occasionally found with bi- and tri-furcated penes (c.f. Bryan et al., 1986).

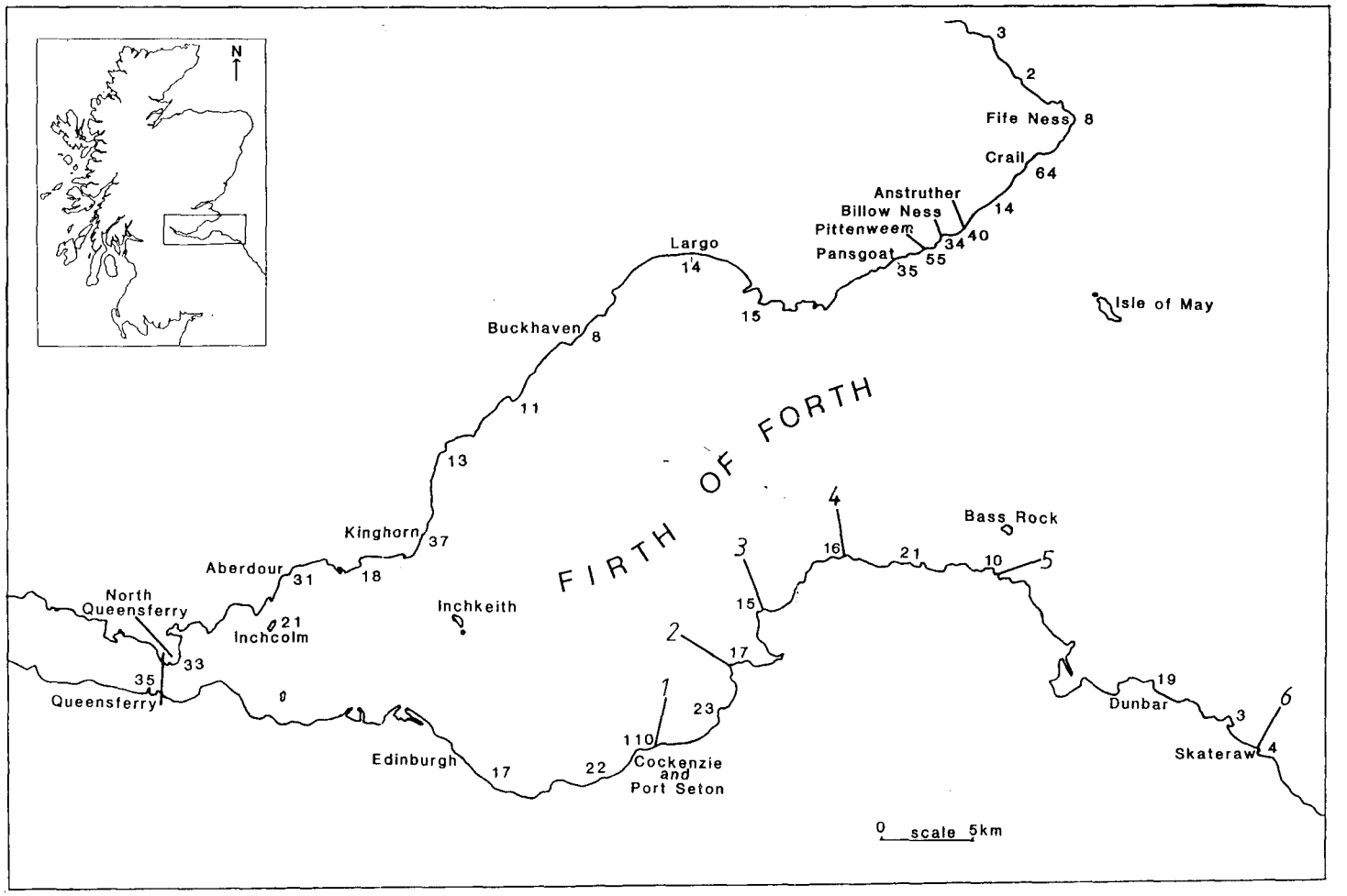

Fig. 1. Geographical distribution of degrees of imposex (%) in dogwhelk populations in the Firth of Forth in 1987, and locations (1–6) of archived samples from 1975.

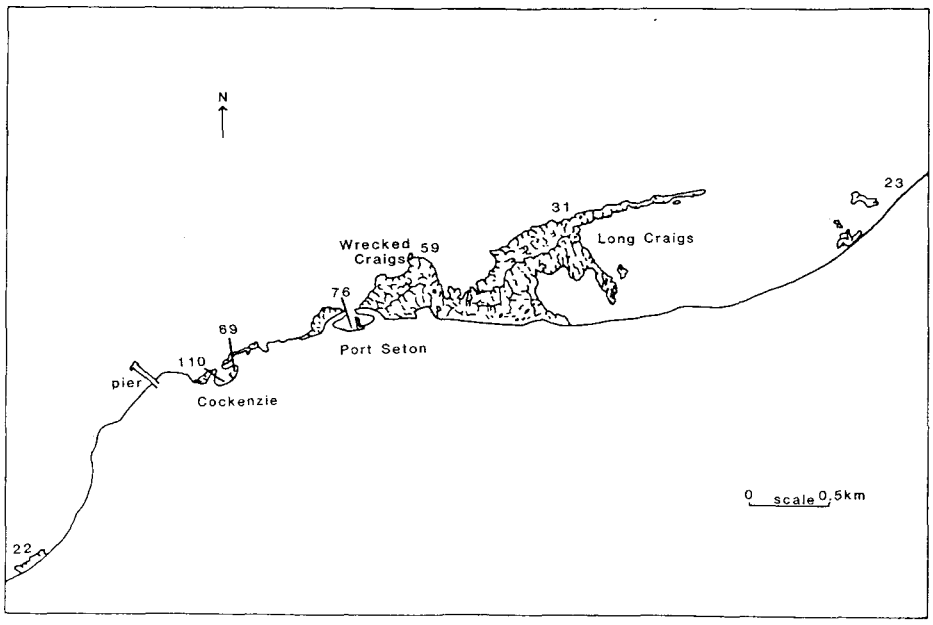

Fig. 2. Geographical distribution of degrees of imposex (%) in the Cockenzie/Port Seton area (Firth of Forth, Scotland).

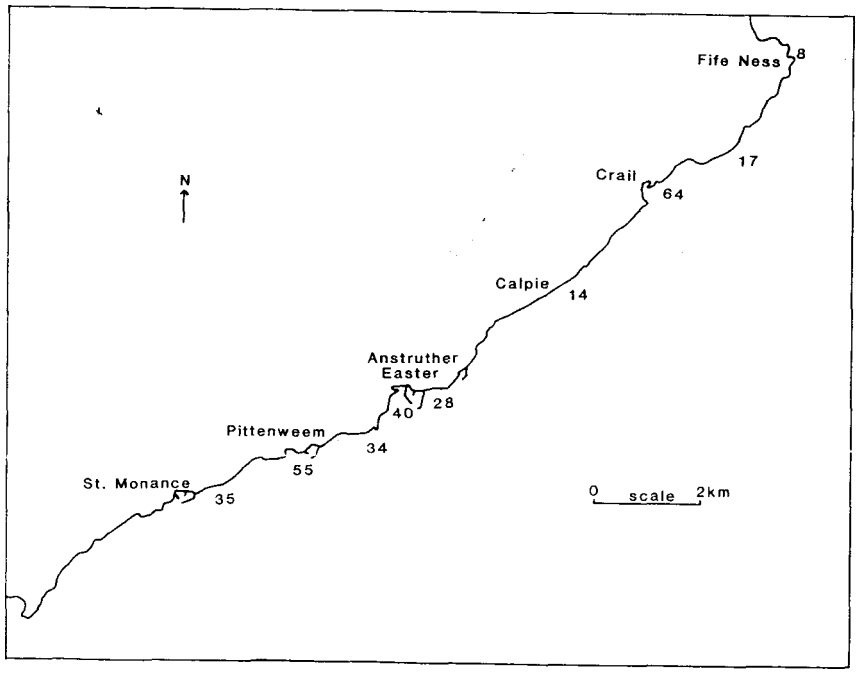

Fig. 3. Geographical distribution of degrees of imposex (%) around fishing harbours in the East Neuk of Fife (Firth of Forth, Scotland).

TABLE 1

Comparison of development of imposex in dogwhelks sampled in 1975 and 1987

Location	Natl Grid Ref.		% females with penis		Imposex %	
	1975	1987	1975	1987	1975	1987
1 Long Craigs	NT415765	413763	80	100	2.0	31.2
2 Craigielaw	NT446800	456805	70	100	0.1	17.0
3 Gullane	NT465834	473833	0	100	0	15.1
4 Dirleton	NT515862	515862	0	100	0	15.9
5 Seacliff	NT610849	609846	30	100	0.4	10.0
6 Skateraw	NT750750	750750	0	95	0	4.4

The degree of imposex (Fig. 1) ranged from 2 to 110%, with a mean value of 23.0%. The degree of imposex was lowest (< 5%) in samples from open North Sea coastal areas beyond Fife Ness and Dunbar. Penis development was most advanced in groups of samples from the Cockenzie/Port Seton region (31–110% imposex, Fig. 2), and the East Neuk of Fife (14–64%, Fig. 3).

Female dogwhelks from three of the sites in the 1975 survey (Table 1) showed no indication of penis development (0% imposex). At the remaining three sites, ~50% of the females showed some indication of penis development, but the degree of imposex was low (< 2%).

DISCUSSION

Tributyltin has entered the marine environment primarily through leaching from antifouling coatings on the hulls of commercial and pleasure craft, from the maintenance (cleaning, scraping and painting) of such vessels, and from antifoulant preparations used in mariculture (DOE, 1986).

The degrees of imposex observed throughout the Firth of Forth in 1987 exceed the values of < 1% reported in areas distant from known sources of TBT (Bryan et al., 1986; Davies et al., 1987), indicating a general contamination of the study area.

In the absence of mariculture operations, the major sources of TBT in the Firth of Forth would be anticipated to be from marinas, small boat anchorages, fishing harbours, boat yards, and large vessels on passage to ports such as Leith, Hound Point and Grangemouth.

Marinas and small boat anchorages

Pleasure craft activity is concentrated in the more sheltered western parts of the Firth, with the main mooring and anchorage facilities being located at Queensferry, Kinghorn, and Aberdour (Fig. 1). The levels of imposex at these locations (31–37%) were higher than those in dogwhelks from adjacent sites and exceeded the overall mean value of 23% for the Firth.

Fishing harbours

The main fishing harbours are on the north coast of the Firth in the East Neuk of Fife (Fig. 3). Imposex is well developed throughout this area, particularly in dogwhelks collected close to the fishing ports at Crail (64%), Anstruther (40%) and Pittenweem (55%). The high degrees of imposex elsewhere (Pans Goat, 35%; Billow Ness, 34%) reflect the close proximity of TBT sources at the harbours.

Boat repair and construction yards

The highest degree of imposex found in the Firth (110%) occurred in dogwhelks collected from rocks adjacent to the slipway at a boat yard in the inner harbour at Cockenzie (Fig. 2). A degree of imposex in excess of 59% was found over a distance of 1.5 km between Cockenzie and Wrecked Craig (Port Seton), but fell to average levels within a further 2 km. The more advanced development of imposex at Cockenzie harbour compared with other harbours in the Firth may reflect an additional input of TBT arising from hull cleaning, scraping and painting at the boat yard (Waldock et al., 1987).

The Firth of Forth is also an important support area for the North Sea oil industry. Oil rigs are brought to Largo Bay for maintenance and repair and rigs are constructed in a yard at Buckhaven. Tributyltin antifoulants are not normally used on oil rigs, however, and this is confirmed by the comparatively low degree of imposex (8–15%) found in the Buckhaven–Largo Bay area.

Despite the general contamination of the Firth by TBT, several local sources can clearly be identified. The high degrees of imposex resulting from these inputs are restricted to small areas and are not identifiable at distances more than 2 km from the sources. The capacity of the receiving waters to dilute and disperse a contaminant input will influence the area over which its effects may be detected. In enclosed waters of Scottish sea lochs, Davies et al. (1987) found that a moderate number of boats or fish cages could result in the contamination of the entire area, but that imposex rapidly fell to background levels (< 1%) in the more exposed coastal areas at the mouths of the lochs. In the more open waters of the English Channel, where there are large numbers of boats, Bryan et al. (1986) reported affected populations 5–10 km from recognised sources of TBT. By contrast, effects were localised in the vicinity of harbours on the exposed north coast of Cornwall.

The Firth of Forth is intermediate in degree of exposure between the sea lochs and the north Cornish coast, and therefore might be expected to resemble the Channel coast in pattern of TBT contamination. As described for the Channel coast, particularly strongly affected dogwhelks are associated with definable sources of TBT (e.g. Cockenzie and the East Neuk of Fife harbours), but between these areas imposex is well above "background" levels. Whilst all the readily recognised sources of TBT within the Forth must contribute to this widespread effect, it is not possible to determine the relative importance of

localised inputs, and more diffuse sources, such as the larger commercial and naval vessels on passage through the Firth.

Dogwhelks available from 1975 were limited to six sites east of Cockenzie on the southern side of the Firth. No penis growth was detected at three of the sites, and in all cases the degree of imposex (1–2%) was much lower than in comparable 1987 samples (Table 1). The degree of imposex found in these populations would now be associated with areas distant from any TBT source. Penis development was found in all but one of the 1987 females and the degree of imposex in these animals decreased eastwards from 31% at Long Craigs (Port Seton) to 4% at Skateraw. It may be concluded that, in 1975, the Firth of Forth east of Cockenzie was largely free from contamination by TBT. However, since 1975 contamination has become widespread, and a number of additional sources has been identified.

The first recognition of imposex in dogwhelks near a marina at Plymouth in 1969 (Blaber, 1970) coincided with the early stages of the rapid expansion in the usage of TBT yacht paints. From the proportion of affected females, Bryan et al. (1986) estimated the degree of imposex in these samples to be $< 5\%$, and made comparisons with 1985 levels of 48–67%. Yachting activity in the Forth is much less intense than in Plymouth Sound, and is concentrated in western areas where marinas have developed since 1979. At the Cockenzie boatyard "free-association" paints were not used, although the TBT-boosted copper paints were used for many years until they were replaced by co-polymer paints in about 1983 (D. Macnamara, personal communication, 1987). The unexpectedly low degrees of imposex east of Cockenzie in 1975 may reflect a comparatively low usage of TBT in the area. The increase in the degree of imposex between 1975 and 1987 coincides with increasing numbers of pleasure craft in the area, and the change on commercial vessels to co-polymer paints containing higher concentrations of TBT.

Recently, comprehensive statutory controls under the Food and Environment Protection Act (1985) have been introduced. From 1 July 1987, paints containing triorganotin compounds were not approved for use on vessels less than 25 m, or fish farm nets and cages. The sale, supply, storage, advertisement and use of TBT paints for these purposes is therefore prohibited, and it is expected that a gradual recovery of the dogwhelk populations from the effects of TBT will now occur.

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