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Tributyltin in the marine environment, with special reference to Nordic waters - A literature survey

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CONTENTS

Summary

Studies on organisms from different phyla of both the animal and the plant kingdom show that effects on tributyltin are diverse and organisms generally respond to quite low levels of tributyltin. The effects are mainly seen in wide range of physiological changes, less growth, higher mortality, abnormal development and deteriorated metabolism. Individual species are, however, quite different in their tolerance towards organotin pollution.

Despite extensive literature on the distribution and effects of organotins in the marine environment the literature on organotin pollution in Nordic waters is scarce. Further, most studies are performed on populations or species living in temperate latitudes and data on persistence of tributyltin and their effects on sub-Arctic and Arctic communities are almost lacking.

Tributyltin pollution is found in most places where it has been searched for in Nordic waters and the effects are pronounced near major harbors. Despite restrictions of the use of tributyltin on ships (<25 m) in Nordic waters, tributyltin seems still to be a major environmental problem in some of these waters. The effects of tributyltin may be expected to exist some time in the future because of tributyltin source in harbors and near-harbors sediments.

There is evident need for studies focusing on:

1) Presence and persistence of tributyltin in sediments at high latitudes.

2) Effects of harbor dredging on dispersal of organotins.

3) Tributyltin contamination in key species in Nordic waters, in time and space.

4) Effects of low concentration of tributyltin on community structure and dynamics of inter- and subtidal benthic communities and planktonic communities.

5) Pathways of tributyltin through sub-Arctic and Arctic communities.

6) Effects of tributyltin on survival of larvae of commercially important fish species.

1. Introduction

Tributyltin has for some time been considered among the most harmful chemicals man places in the oceans (Goldberg 1986). This is mainly because of the pronounced effects of this chemical at low level concentrations, first seen in the breakdown of the French oyster industry in the late seventies (Alzieu et al. 1980, Alzieu 1991, Anonymous 1991). Tributyltin is presently considered a global pollutant (Ellis and Pattisina 1990), not surprisingly considering the global use of the chemical on commercial ships and pleasure crafts. There is increasing demand for further restrictions of its use on larger vessels, the substance presently being banned on vessels <25 m in large part of the world. There is further increased scientific interest in studies of the effects on tributyltin on individuals marine species and communities.

2. Objective

The objective of this literature survey was to evaluate the distribution and effects of tributyltin in the marine environment, with particular reference to Nordic waters. The Nordic waters are here considered the waters surrounding the Nordic countries.

This literature survey is based mainly on papers published in the international literature. The papers were found by searching major journals over the last five years, and by thorough searches in library data bases. Literature prior to 1991 was consulted when necessary. The impact of tributyltin in the marine environment has recently been reviewed by Bryan and Gibbs (1991), who treated especially the literature prior to 1991

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3. Distribution, dispersal and persistence

Tributyltin has been in use since the late 1950s as constituent of antifouling paints. Its use in the marine environment has mainly been on ship hulls, docks and on sea pens for salmon farming. The substance is presently used in self-polishing antifouling paint. Comparison of input from commercial shipping and from pleasure crafts shortly before tributyltin was banned on ships <25 m, indicated that the contribution was considerably higher from the pleasure crafts than from commercial ships at that time (Cleary and Stebbing 1987).

The substance has widely been banned on vessels <25 m (e.g. in France since 1982; in Britain since 1987; in Iceland and Canada since 1990; in Sweden since 1991). As result of the ban tributyltin in the water column decreased in Arcachon Bay, France (Alzieu 1986). In Chesapeake Bay tributyltin decreased linearly over 3 years after the ban (Evans and Huggett 1991).

The maximum concentration of tributyltin is found in the surface microlayer (Cleary and Stebbing 1987). There the tributyltin is adsorbed by surface-active organic matter, the polar, monomolecular layers acting as sites for accumulation of lipophilic pollutants. The accumulation of tributyltin in the surface microlayer has major implications for intertidal areas, where deposition on the shore occurs at low tide (Quevauviller et al. 1989). This may be the major reason for extremely high tributyltin concentrations found in some intertidal bivalve species (i.e. in *Mya arenaria*, see Bryan and Gibbs 1991). Curtis (1994) suggested on the basis of imposex in *Ilyanassa obsoleta* that lower intertidal habitats were less exposed to tributyltin than the higher parts of the intertidal.

In the mid 1980s subsurface concentrations of tributyltin in the UK ranged from <1 ng/l to >1000 ng/l in estuaries, while open waters had 10-100 ng/l (Bryan and Gibbs 1991). The surface microlayer had 2 to 27 times the subsurface concentration (Cleary and Stebbing 1987). It has to be borne in mind here that measuring tributyltin in the water column may be difficult at concentrations below 20 ng/l (Readman and Mee 1991).

The concentration of tributyltin in the water column is often highly seasonal, depending on the seasonal use of smaller boats (Hall et al. 1987, Langston et al. 1987, Alzieu et al. 1989, Evans and Huggett 1991, Oehlmann et al. 1993). This seasonal variation may locally be decreasing, following restrictions on the use of tributyltin on vessels <25 m (see data in Dahl and Blanck 1992). Despite a ban in France in 1982, a clear seasonal pattern in water column concentrations is still seen (see data in Oehlmann et al. 1993).

Sediment near harbor often contains high concentrations of tributyltin, but the variability is high (Stewart and de Mora 1990, Dowson et al. 1992). Surprisingly, there is lack of data evaluating the role of harbor dredging on dispersal of tributyltin, as harbor or near-harbor sediment may be future source of tributyltin.

The degradation of tributyltin is dependent on the temperature of the environment, being slower at lower temperature, presumably because colder temperatures inhibit the growth of tributyltin-degrading microorganisms (Stewart and de Mora 1990). To date nothing has been published on the persistence of tributyltin in water column and sediments in cold-water areas, i.e. at high latitudes. In light of the slow degradation of tributyltin at low temperatures, it is important to evaluate its persistence and degradation at high latitudes.

Tributyltin is transformed by two pathways: methylation and debutylation (Yonezawa et al. 1994). During anaerobic incubation the methylation was mainly supported by sulfate reducing activity, while debutylation was mainly supported by nitrate reducing activity (Yonezawa et al. 1994). Tributyltin can accumulate to concentrations, which can probably inhibit biological degradation (Stewart and de Mora 1990). Tributyltin is more persistent in the sediment than the water column, and its half-time in the sediments may be from several months to over decades, depending on the concentrations present. Tributyltin deposited over 15 years ago can still be detected (de Mora et al. 1995). Desorbtion of tributyltin from the sediment may occur after sediment disturbance (Dowson et al. 1992) and it is likely that aquatic sediment acts both as a sink and as a potential source of tributyltin. Depth concentration profiles of tributyltin differ considerably between localities (De Mora et al. 1989, Sarradin et al. 1994). Hydrodynamical perturbation of sediment layers may result in mixing of new and old sediment and burial of tributyltin.

Tributyltin has been detected in sediments at a water depth of 377 m (Stewart and Thompson 1994), so this pollutant may affect even the deep-water fauna. There are, however, no studies on effects of tributyltin on deep-waters faunas or even studies on body burdens of tributyltin within deep-water species.

4. Effects on marine organisms

4.1. Bivalve molluscs

The first reports on effects of tributyltin on bivalves originate from France (Alzieu et al. 1980). Tributyltin induced malformation in the adult Pacific oyster, *Crassostrea gigas*, cultured in France (Alzieu et al. 1980). The French oyster industry collapsed suddenly in 1977 to 1979 and resulted in the loss of 700 millions francs. Since restrictions on the use of tributyltin came into effects, concentrations have lowered enough to allow resumption of mariculture in certain places (see for instance Dyrynda 1992).

The effects on the oysters are diverse. The shells become thickened because of growth of additional layers of shell, which are separated by chambers filled with gelatinous material (Alzieu 1986). Highly thickened shells may contain only a little soft tissue. This pattern of shell thickening is initiated at quite low concentrations of tributyltin (2 ng/l; Alzieu et al. 1989). Tributyltin also affected the survival and growth of oyster larvae.

The larvae of the blue mussel *Mytilus edulis* are sensitive to tributyltin (Beaumont and Budd 1984) and the lowest-observed-effect concentration of tributyltin was 0.05 μg/l, and 20 μg/l for dibutyltin (Lapota et al. 1993). Though adult *Mytilus edulis* seem to withstand quite high concentrations of tributyltin in field, at threshold concentrations of 3 to 4 μg tributyltin/g tissue dry-weight feeding is significantly reduced and severe inhibition of growth occurs above 4 μg TBT/g (Widdows and Page 1993). The sublethal and lethal effects of tributyltin measured in terms of physiological energetic responses, are thus comparable for larval and adult *Mytilus*. *Mytilus edulis* is, however, an order of magnitude less sensitive to tributyltin than the dogwhelk (*Nucella lapillus*), in which tributyltin induces imposex (Widdows and Page 1993).

Zuolian and Jensen (1989) studied the rate of accumulation of organic and inorganic tin in *Mytilus* in the field. They showed both rapid accumulation of tributyltin and further rapid break-down of organotin residuals in the tissue of *Mytilus*.

Bryan and Gibbs (1991) provide data on concentrations of TBT within tissue of number of other bivalves. They show that *Mya arenaria* in particular has high concentration of TBT, and a bioconcentration factor of over a half a million. *Mya arenaria* is common in tidal flats in northern Europe and is important food for some bird species (e.g. oyster catchers). Whether high concentrations of tributyltin in intertidal animals has pronounced effects on birds, remains to be studied in detail.

The decline of populations of the bivalve *Scrobicularia plana* is of particular concern. This bivalve, which occurs in estuaries in the Northeast Atlantic, has virtually disappeared from many places (Ruiz et al 1994a, Ruiz et al. 1994b). This species settles readily in sediments which are contaminated by tributyltin, but the pollutant reduces growth considerably. The juveniles are forced by their size to stay in shallow sediment layers and will suffer high mortality rate because of predation and exposure (Ruiz et al. 1994b). The diminished growth will also prolong time until reproductive maturity and delay incorporation to the reproductive stock of the population (Ruiz et al. 1994a).

4.2. Gastropod snails

The presence of imposex is probably the most extensively used indicator of tributyltin pollution. Imposex (imposed sex) was first described by Smith (1971, 1981a, b), and has now been reported from 72 species of prosobranch gastropods, from 49 genera (Fioroni et al. 1991). This phenomenon is seen in development of male characteristics (penis and vas deference) on female individuals. This phenomenon has been studied most extensively in dogwhelk (*Nucella lapillus*) in Great Britain and France (Bryan et al. 1986, Gibbs and Bryan 1986, Gibbs et al. 1987, Davies et al. 1987, Gibbs et al. 1988, Bailey and Davies

1989, Bailey and Davies 1991, Gibbs et al. 1991, Spooner et al. 1991, Stroben et al. 1992b). Studies of the presence of imposex have revealed that organotin pollution is now occurring worldwide (Alvarez and Ellis 1990). Recent findings have shown the presence of imposex in Southeast Asia (Ellis and Pattisina 1990) and data are accumulating from Australia (Nias et al 1993, Wilson et al. 1993). The general use of imposex as bioindicator of tributyltin has, however, recently been questioned (Evans et al. 1995). Imposex may not be as specific for tributyltin pollution in all gastropod snail as previous suggested. Copper and environmental stress can induce imposex in *Lepsiella vinosa* (Nias et al. 1993).

Studies on *Buccinum undatum* in the North Sea have shown that the degree of imposex in highest near major shipping routes (Ten Hallers-Tjabbes et al. 1994). The gastropod *Nucella lima* showed decline in imposex frequency with increased distance from a marina in Auk Bay, Pacific coast of Alaska (Short et al. 1989). Similar findings are for *Nucella lapillus* (Bryan et al. 1986, Gibbs et al. 1991, Svavarsson and Skarphéðinsdóttir 1993, 1995).

Stroben et al. (1992a) have provided a general scheme of imposex development within prosobranch gastropods. The morphological changes follow a few main developmental lines (Stroben et al. 1992a). In most studied species vas deference grows from the base of penis towards the opening of the vagina. In *Nucella lapillus* the vas deference develops from two centers (Gibbs et al. 1987).

The effects of tributyltin may subsequently lead to sterility of the snails. The sterility may, however, be caused by different abnormalities. In *Nucella lapillus* and other closely related species sterility is accomplished by overgrowth of the female aperture by vas deference (Gibbs et al. 1987). Sterility may also be caused by split bursa copulatrix or capsule glands. This has been found in *Ocenebra erinacea* and *Urosalpinx cinerea* (Gibbs et al. 1990, Gibbs et al. 1991, Oehlmann et al. 1992). Female sterility may result in disappearance of the species form the polluted area, and is well documented for *Nucella lapillus* (Bryan et al. 1986). This may also be so for *Lepsiella scobina* in New Zealand (Stewart et al. 1992). Some common species of gonochoristic, intertidal snails seem to be unaffected by organotins. *Littorina littorea* showed no signs of developing male characteristics, despite being found in polluted areas where other gastropods (*Nucella* *lapillus* and *Ocinebrina aciculata*) showed imposex quite commonly (Deutsch and Brick 1993).

In addition to the development of imposex the female gastropod snails also have cell changes in the penis epithelia (Brick and Deutsch 1993). The female cells have degenerated structures with enlarged nuclei, irregular extended mitochondria with a loss of cristae and a general reduced number of organelles.

Following legislation prohibiting the use of tributyltin on ships <25 m there has been marked recovery in dogwhelk populations (*Nucella lapillus*) in British waters (Evans et al. 1991, Evans et al. 1994, Evans et al. 1995) and in Canadian populations of *Nucella emarginata*, *Nucella lamellosa* and *Nucella canaliculata* (Tester and Ellis 1995).

4.3. Crustaceans

Effects of organotins have been studied on decapods (*Homarus americanus* and *Hemigraspus nudus*, Laughlin and French 1980; *Rhithropanopeus harrisii*, Laughlin et al. 1983; *Uca pugilator*, Weis et al. 1987; *Palaemonetes pugio*, Clark et al. 1987; Khan et al. 1993), amphipods (*Gammarus oceanicus*, Laughlin et al. 1984; *Rhepoxynius abronius*, *Eohaustorius washingtonianus* and *E. estuarius*; Meador et al. 1993), cladocerans (Polster and Halacka 1971) and copepods (*Nitocra spinipes*, Linden et al. 1979; *Acartia tonosa*, U'Ren 1983). These studies focus mainly on lethal and sublethal doses of organotins. The effects are not particularly well defined.

Exposure of juvenile *Gammarus oceanicus* to 3 μg/l of TBTO for 8 weeks resulted in 100% mortality, while significantly reduced survival occurred at 0.3 μg/l (Laughlin et al. 1984). For the copepod *Acartia tonosa* the threshold value of acute toxicity was below 0.3 μg/l of TBTO and 96 h LC_{50} was 1.0 μg/l of TBTO (U'Ren 1983). The LC_{50} values for the harpacticoid copepod *Nitocra spinipes* were 2 μg/l (Linden et al. 1979), while the 46 h LC_{50} for the caldoceran *Daphnia magna* was 3 μg/l (Polster and Halacka 1971). Amphipods show significant mortality at tissue levels between 50 and 80 μg tissue dry-weight (Meador et al. 1993). Different amphipod species show different tolerances towards tributyltin and also different bioconcentrations. These differences have been related to reduced uptake and ability to metabolize tributyltin. Furthermore, the same species may show different responses towards tributyltin and this variability may occur over the natural, seasonal cycle of physical variation, that occurs in populations (Meador 1993). For the amphipods *Rhepoxynius abronius* and *Eohaustorius estuarius* the LC_{50} decreased 2 to 3 fold for animals held for several weeks in the laboratory versus those recently collected form the field (Meador 1993), and this may be related to declining lipid concentrations. Lipid concentrations may control body burdens within the amphipods because of the lipophilic nature of tributyltin (Meador 1993).

There is little data on effects of organotins on crustacean development. The shrimp *Palaemonetes pugio* showed significantly slower telson regeneration at 0.5 µg/l TBT than controls, while shrimps kept at 0.1 and 0.3 µg/l showed no significant differences from controls (Khan et al. 1993). Fiddler crabs (*Uca pugilator)* showed similarly retarded limb regeneration and various deformities at 0.5 µg/l (Weis et al. 1987).

In light of the important role of copepods in the planktonic ecosystem, the scarce literature on the effects of tributyltin on their development is surprising, bearing in mind the high concentrations found near the surface layer. Further research on plankton copepods and other constituents of the planktonic ecosystem should be initiated.

4.4. Fish

Fishes are potential target for tributyltin pollution, partly because their larval development often occurs in the upper water column, where high amounts of organotins are found (Cleary and Stebbing 1987), and also because many species have juvenile stages living in coastal areas.

Organotin-based antifouling paint has extensively been used on salmon sea pens in the past, and organotins have presumably reached human diet in the United States through caged fish (Short and Thrower 1986). There are, however, only a few studies of effects of tributyltin on marine (Ward et al. 1981, Holm et al. 1991) and freshwater fishes

(Chliamovitch and Kuhn 1977, Josephson et al. 1989, Martin et al. 1989). Bryan and Gibbs (1991) give data on tributyltin and dibutyltin concentrations in flounder (*Platichthyus flesus*) from Sutton harbor, Plymouth, and report rather high concentrations.

The effects of organotins on fish have mainly been studied on caged fish. Juvenile Chinook salmons rapidly accumulate tributyltin and high bioconcentrations are to be expected in the muscles because of relatively high lipid contents (Short and Throver 1986). Effects of tributyltin are mainly seen in damages of gills and liver and it has been suggested that it affects gill lipogenase (Josephson et al. 1989), NaK-ATPase and Mg-ATPase (Pinkney et al. 1989). Tributyltin may alter both cytochrome P450 dependent metabolism and induction response to other environmental pollutants (Fent and Stegeman 1993). Holm et al. (1991) did not find that the reproduction of the three-spined stickleback (*Gasterosteus aculeatus*) to be affected by tributyltin.

There are, surprisingly, no studies on effects of tributyltin on the survival of fish larvae.

4.5. Other studies

There are published studies on many invertebrate phyla, including poriferans, coelenterates, polychaetes, bryozoans, echinoderms and tunicates (Henderson 1985, Bryan and Gibbs 1991, Gianguzza et al. 1993). Most of these studies are discussed in detail by Bryan and Gibbs (1991) and are mainly concerned with toxicity of tributyltin.

There is accumulating evidence of sensitiveness of bacteria, protozoans and lower invertebrates to organotins (Suzuki et al. 1993, Saint-Louis et al. 1994, Uchida 1994). The tolerance of bacteria towards tributyltin pollution may depend upon habitats. Tolerance of bacteria in sediment samples was higher towards TBTO than bacteria from water samples of the same locality (Uchida 1994). There was rapid uptake of tributyltin in continuous culture of the unicellular alga *Pavlova lutheri* exposed to tributyltin, seen in the cellular fluid (Saint-Louis et al. 1994). Due to its ability to bioaccumulate large quantities of organotin without being irreversibly affected, it might play an important role in the uptake of organotins by the filter-feeders which feed on *P. lutheri*. The cell density and growth rate of continuos culture of *P. lutheri* were not affected by a contamination level of 18.5 nmol/l of tributyltin, but at 74 nmol/l the culture suffered a toxic impact seen in loss of 40 % of the cell density (Saint-Louis et al. 1994).

Brief exposure of the protozoan *Euglena gracilis* towards tributyltin chloride led to rapid incorporation of the pollutant, which was mainly located in the cytosol and microsomes fraction (Suzuki et al. 1993). The cells further changed their shape into cyst form and became almost inactive within minutes.

Recent studies on effects of tributyltin on marine sponges show that tributyltin induces apoptosis (cell death in which the cells actively participate in the process of dying) in the sponge *Geodia cydonium* (Batel et al. 1993).

Organotins have earlier been experimentally shown to be quite harmful to mammals (Noda et al. 1992). Organotin compounds have recently been observed in the blubber of marine mammals (Iwata et al. 1994). Butyltin compounds were found in seven species of marine mammals including Dall's porpoise (*Phocoenoides dalli*), finless porpoise (*Neophocaena phocaenoides*), common dolphin (*Delphinus delphis*), spinner dolphin (*Stenella longirostris*), ginkgo-toothed beaked whale (*Mesoplodon ginkgodens*), killer whale (*Orcinus orca*) and largha seal (*Phoca largha*). Highest residuals were in mammals in coastal waters. Butyltin compound were not detected in minke whale (*Balaenoptera acutorostrata*) from the Antarctic Ocean (Iwata et al. 1994).

Only a few records exist of studies on marine multicellular algae. The seaweed *Fucus vesiculosus* is a poor accumulator of organotins, compared to the polychaete *Nereis diversicolor,* and some mollusks (Langston et al. 1987). Lindblad et al. (1989) showed, however, that *F. vesiculosus* is strongly effected by tributyltin and changes were obvious in oxygen production and decreased nutrient uptake at levels as low as 0.6 µg/l. The latter studies were performed both at a low (6.3 ‰) and fairly high (26.5 ‰) salinity. Lindblad et al. (1989) concluded that tributyltin additions to the marine environment would probably lead to decline of the *Fucus vesiculosus*. The effects of low level of tributyltin on *Fucus vesiculosus* are of particular concern. The fucoids are dominant algae on many rocky shores in sub-Arctic and Arctic waters (see for instance Hansen and Ingólfsson 1993) and changes is their distribution may seriously affect the associating flora and fauna.

Ongoing research on periphyton communities in Sweden show that since the ban on use of tributyltin in these waters the periphyton communities are much less affected by tributyltin than they were prior to the partial ban (Dahl and Blanck 1992).

5. Studies on tributyltin pollution in the Nordic countries

Though organotins have for some time been considered among the most harmful chemicals in the marine environment, only a few published reports are on its distribution and effects on the Nordic marine fauna and flora. Most of these studies were mentioned here earlier. The need for further research in Nordic and Arctic waters has recently been stressed (Knutzen 1993, Anonymous 1994).

Jensen and Zuolian (1987) give data on sea-water organotin around marinas in the Sound, Denmark. Björklund (1988), Dahl and Blanck (1992), and Granmo and Ekelund (1993) give data on tributyltin in the sea around Sweden.

Studies on the marine flora of Nordic waters have focused on the effects of tributyltin on *Fucus vesiculosus* (Lindblad et al. 1989) and on a periphyton community (Dahl and Blanck 1992).

Gibbs et al. (1991) reported on findings of imposex in *Nucella lapillus* at two locations in Western Norway (Bergen, Egersund). Harding et al. (1992) reported on widespread organotin pollution in Western Norway and in Skagerrak. They measured tributyltin in *Nucella lapillus* and registered imposex frequency. These studies show that severe tributyltin pollution is occurring in Norway. The Norwegian localities have VDSI (vas deference sequence index; 0 = no pollution effects, 6 = maximum pollution, 5-6 indicates sterile females) above 4. Recent studies in Iceland show that imposex in *Nucella lapillus* is widely distributed along the west coast of Iceland (Svavarsson and Skarphéðinsdóttir 1993, 1995). On the Reykjanes peninsula imposex was found on 23 of 28 studied localities. Imposex was also recorded at eight out of nine studied localities on the sparsely populated West fjords. Imposex has also been found within the netted dog whelk *Nassarius reticulatus* in Sweden (Gisela Holm, pers. comm., Laughlin and Lindén 1987). Brick and Bolte (1994) mention imposex in the common whelk (*Buccinum undatum*) in Svalbard, Norway, this being also reported from the White Sea (Kantor 1984).

Tributyltin has been measured in *Mytilus* at different localities around Sweden, prior to and after the ban of its use on ships <25 m occurred in Sweden (Björklund 1986, 1987, Ekelund and Granmo 1993, Granmo and Ekelund 1993). Svavarsson and others (in preparation) measured tributyltin in *Mytilus edulis* at 18 locations in western Iceland. The rate of accumulation and depuration of tributyltin in *Mytilus edulis* in a Danish harbor was studied by Zuolian and Jensen (1989).

Effects of tributyltin on the amphipod *Gammarus oceanicus* and the harpacticoid *Nitrocra spinipes* were studied in the Baltic (Linden et al. 1979, Laughlin et al. 1984).

There are no published records of studies on the effects of organotins on caged fishes in Nordic waters, despite the fact that fish cages have been extensively used in Nordic mariculture. Further, there are only a few studies on commercially important marine fish species. In Nordic waters effects of tributyltin have only been studied on the three-spined stickleback (*Gasterosteus aculeatus*) in coastal waters of Sweden (Holm et al. 1991), and organotins have been detected in *Platichthys flesus* and *Hippoglossoides platessoides* (Björklund 1988). Organotins were not detected in the Baltic herring (*Clupea harengus*) (Björklund 1988).

Recent studies on tributyltin in Nordic waters show that tributyltin is still a major environmental problem, despite its restricted use for some years. It is apparent from the frequency of imposex that tributyltin pollution occurs in some quantity even in sub-Arctic and Arctic waters, but it is magnitude of this pollution is still unknown.

6. Recommendation of important fields of future research

The widely occurring effects of organotins in the marine environment are of major concern. It has been argued that the present restriction on the use of organotins may not be sufficient to protect coastal ecosystems (see Alzieu 1991). From this literature survey there is evident lack of data concerning effects, persistence and distribution of tributyltin in general and studies in Nordic waters and particularly at high latitudes are scarce. The following fields of study are considered among the most important:

1) Presence and persistence of tributyltin in sediments at high latitudes.
The low temperatures in Arctic and sub-Arctic waters indicate a slow degrading of tributyltin in this environment.

2) Effects of harbor dredging on dispersal of organotins.
Previous studies on persistence of organotins in harbor and near-harbor sediment suggest that these may act as source for tributyltin for some years in the future and it is evident that although the use of organotins may be much restricted (only used on ships >50 m) or even globally banned, these may continue to have effects for the next decade.

3) Tributyltin contamination in key species in Nordic waters, in time and space.
More basic data is needed of levels of tributyltin concentrations in important species at different seasons and under different conditions.

4) Effects of low concentration of tributyltin on community structure and dynamics of intertidal and subtidal benthic communities and the planktonic community.
Serious lack of data is on effects of tributyltin on planktonic organisms (phytoplankton and zooplankton). Incorporation of tributyltin in benthic communities is badly known. The lack of wide spectral research on tributyltin in Nordic waters is of major concern. Many intertidal bivalve molluscs have been shown to contain substantial amounts of tributyltin

(i.e. *Mya arenaria*, see Bryan and Gibbs 1991) and some of these species are important food for birds. The impact of this needs to be evaluated.

5) Pathways of tributyltin through sub-Arctic and Arctic communities.
No data is available on the subject. Studies on tributyltin are listed among needed in the Arctic (Anonymous 1994).

6) Effects of tributyltin on survival of larvae of commercially important fish species.
Despite their national economical importance fishes have received only a minor attention in studies of organotins. The susceptibility of marine fishes towards organotin pollution may particularly be during their larval stages, at which the larvae occur in the upper water column where high concentrations of organotins may be found. Further because young fish may forage in the *Laminaria* forests near harbor areas.

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