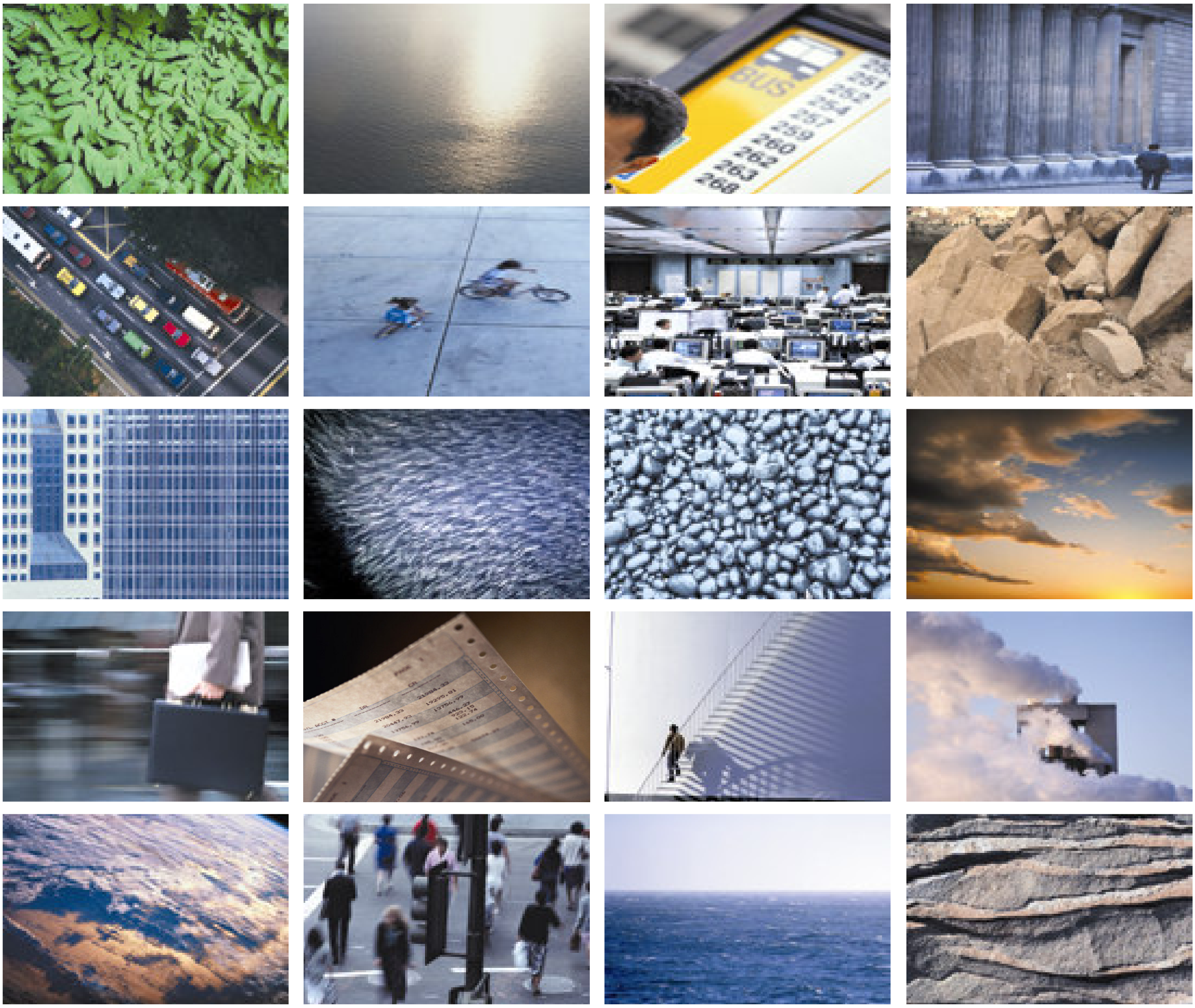

Ecotec-STC

Ecospeed: Risk evaluation for the spread of "alien species" in surface water when using hard coatings on ship hulls

December 2008

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Report

Hydrex NV

Ecotec-STC:
Ecospeed: Risk evaluation for the spread of "alien species" in surface water when using hard coatings on ship hulls

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For and on behalf of ERM nv

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INHOUD

1. SETTING 3

2. INTRODUCTION 4

2.1 SCOPE 4

2.2 METHODOLOGY 4

2.3 INTRODUCTION 4

2.4 BIOFILM VERSUS BIOFOULING 5

2.4.1 Biofilm 5

2.4.2 Biofouling 6

3. ECOSPEED AND BIOFOULING 7

3.1 STATUS 7

3.2 RISK EVALUATION ON THE SPREAD OF SPECIES 7

3.3 GLOBAL RISK ASSESSMENT 8

3.4 CONCLUSION 10

4. BIBLIOGRAPHY 11

Non-technical summary

This report was conceived as an interim report in the framework of the Ecotec-STC Life project. The aim of this Life project is to demonstrate the economical and ecological advantages of a new, hard ship coating "Ecospeed". To this end, the characteristics of Ecospeed will be compared with the common ship coatings. An important distinguishing feature of hard coatings is that they are applied for the entire life span of a ship. Moreover, hard coatings do not contain substances to prevent biofouling on ship hulls, so none of these chemical substances are released.

In May 2008, a lab scale test was performed to investigate the potential release of chemicals after the application of Ecospeed. The results of the chemical analyses demonstrated only small levels of releases. However, concern exists about the risk of the introduction of foreign species ('aliens') through the biofilm. This biofilm builds up, especially when ships are moored.

Since there are no feasible methods known to evaluate this process directly, it was decided to perform a risk assessment based upon a literature review.

The literature research concentrated on the composition of a biofilm to investigate the mechanism of settlement and spread of species. During the first phase of this investigation it was found that the first, thin layer consists mainly of micro-organisms. No problems with new introduced micro-organisms were reported in literature. Macro-organisms only settle the biofilm after a while. The risk for the spread of these macro-organisms (animal or plant) only arises when mobile spores are formed.

Moreover, it was verified if aliens are still spread today by ship hulls and apparently, this is still the case, especially near grids and openings in the hull.

Based on the performed labscale tests and the literature research it was concluded that the use of Ecospeed combined with under water cleanings does not entail an elevated risk for the spread of foreign species compared to conventional coatings. Regular inspections allow timely detection of biofouling on hidden places and removal of this fouling during under water cleanings. Based on studies performed on conventional coatings, it was concluded that an early removal of arising biofouling by under water cleaning ([1]) offers a better protection against the spread of alien species.

[1] An alternative is cleaning in dry dock. However, due to economical constraints (loss of time for the ship) and the absence of infrastructure (sufficient capacity in dry dock in all ports), this is not considered as a feasible option.

1. SETTING

This report was conceived as an interim report in the framework of the Ecotec-STC Life project. The aim of this Life project is to demonstrate the economical and ecological advantages of a new, hard ship coating "Ecospeed". To this end, the characteristics of Ecospeed will be compared with the common ship coatings. An important distinguishing feature of hard coatings is that they are applied for the entire life span of a ship. Moreover, hard coatings do not contain substances to prevent biofouling on ship hulls, so none of these chemical substances are released.

Based on the available interim results of *in situ* and *lab scale* tests, the environmental impact of the potential release of chemical compounds by the Ecospeed coating seemed to be rather small. Besides, the growth of organisms on ships coated with Ecospeed was rather limited. An important prerequisite of the success of this new coating is the regular removal of the incipient fouling on the ship hull. From an economical point of view, this is feasible by using under water techniques. During these under water treatments, the biofouling on the ship hulls is removed. Today however, these under water techniques are no longer allowed in many countries within Northern Europe because they gave rise to the accumulation of pollutants in ports. It concerns chemical compounds which were released out of the previous applied coatings during the removal of biofouling on ship hulls.

The results of a lab scale test ([1]) demonstrated only small levels of releases of chemical compounds; this aspect is only of limited or negligible importance for the Ecospeed coating. However, the question arises if the removal of this preliminary fouling does not entail an elevated risk on the spread of "alien species". The report at hand contains the risk evaluation for the spread of "alien species" in surface water when using hard coating on ship hulls combined with under water cleanings.

[1] Biocidevrije 'antifouling' voor schepen, Emissies vanuit de onderwater coating 'Ecospeed', WD rapport 2008.057, Rijkswaterstaat, 15 november 2008.
=> A (not official) translation of this report is available: "Biocide free 'antifoulings' for ships, Emissions from the underwater coating 'Ecospeed', ERM, December 2008."

2. INTRODUCTION

2.1 SCOPE

The impact study is conducted based on the following assumptions:

- No significant fouling can be detected if cleaning activities are performed timely; and
- During underwater cleaning, the biofilm is released, so a risk of transfer of foreign biological species to other regions arises.

The aim of this study is to investigate the risk of the spread of foreign organisms during under water cleaning. The available literature on the subject and other generally accessible information sources (internet) were consulted during this investigation. It was assumed that the coating is cleaned timely. So, a biofilm might be present, but no clear developed fouling occurs on the ship hull.

2.2 METHODOLOGY

After having discribed the issue of foreign species (so called “alien species”), we go more deeply into the prevention of the introduction of alien species. Then the mechanism of growth on ship hulls is being described. Hereby, special attention is given to the species composition and the herewith related risks of migration of the alien species.

Afterwards the Ecospeed antifouling is shortly described and it is explained how this paint concept is linked to the problem of alien species. Next, this risk is described and assessed by means of literature data. The risk is then compared to the risks of migration of alien species as documented today in the literature, and as such based upon other paint types.

2.3 INTRODUCTION

Overgrowth of ship hulls is often associated with thick layers of acorn barnacles, barnacles and big seaweeds that are stuck on the hull. This results in the fact that the ship experiences a bigger resistance and therefore will use more fuel. At the same time it often also has a negative impact on the corrosion protection of the hull.

In order to prevent this problem, the ship hull will be cleaned on regular basis, or will be treated with a layer of paint that prevents this overgrowth, or a combination of both.

Apart from the influence of the growth on the moving efficiency, in the past this resulted a few times in the introduction of foreign organisms in other regions. The introduction of new species often has negative consequences for the local biodiversity or can strongly disrupt the local ecosystems.

This often has direct or indirect implications. These phenomenons are frequently documented in the literature.

Besides wanted introductions, most introductions of non local species happen through ballast water. At the moment different authorities are discussing measures to further limit this distribution path through international agreed measures.

The route through anchoring to a ship or other floating structures is limited, but certainly not negligible. In the past, the risk was limited by the use of paints that gradually release a substance that prevents the growth for the most part. However, this approach has often led to high concentrations of environmental damaging substances in the sediments and does not totally exclude the potential distribution path.

Since measures are being taken to reduce the use of these toxic paints the research for alternatives was stimulated.

One of these solutions is the use of a hard coating. Once the coating is applied, it can stay on for the normal life span of the ship. This contrary to the other solutions that have to be applied regularly.

In the framework of the Life project it is being examined what the possible environmental impact of the hard coating Ecospeed is.

In situ tests with a few ships show that hardly any growth can be found (as long as the ships do not lie at rest for too long) and that the growth found exists of a slime layer, what corresponds to the first phase of colonisation prior to the settlement of other organisms.

2.4 BIOFILM VERSUS BIOFOULING

2.4.1 Biofilm

A biofilm community which originates on a submerged object is a typical phenomenon. The speed at which this happens and the evolution in the development of the biofilm differ according to the depth and warmth of the waters.

Hereafter, we describe this process. Mind, the origin of a biofilm is not an easy process and depends on many different factors.

A **biofilm** is a structured layer of micro-organisms, often bacteria, surrounded by a self-produced slime and attached to a surface. This slime layer is also called EPS or "Extracellular Polymer Substance". Biofilms often appear in nature and are typically characterised by their way of attachment, a structural heterogeneity, a complex interaction within the community and an extracellular matrix of polymer substances.

A biofilm usually consists of bacteria that attach themselves to the hull (Lee, 2008). These bacteria can only be formed in a sufficiently nutricious environment, but water in the harbour docks and the sea is mostly well provided with all sorts of organic matter and minerals, and therefore form a suitable environment for the bacteria to withdraw nutrients from. This biofilm is sometimes also called the primary slime layer.

Certain pebble weets and other micro algae (blue-green algae,…) are able to form this biofilm by themselves or together with the bacteria (typical groups are the *Thiobacilli* and *Bacillariophyceae*).

Once the biofilm is sufficiently thick, mostly determined by the temperature of the water in combination with the timeframe, a medium is formed whereupon algae and sea acorns can possibly settle. Once these lasts have been well developed, the film is also suited for molluscs, sea urchins, sponges, anemones, bryozoans, colonies of worms,…

This initial formation process of a biofilm, is not a random succession, but is being controlled by numerous physical and biochemical processes. It is known that sea acorns can be attracted by a biofilm or even so can be repelled, depending on the biochemical signals of the biofilm (O'Connora, 1998).

The circumstances allowing a bacterium such as *Bacillus thuringiensis* to attach itself to a substrate (Faille, 1999), as well as the process of sea acorns and mussels is very well documented in literature (cf. Ramsay, 2008). Turbulences as well as type and colour of the substrate were examined. In this way, a wide range of organisms were documented (*Pseudomonas fluorescens, Dreissena polymorpha,…)* (Bott, 1983; Dobrovesky, 2000). Biofilms appear till great depth, even though at greater depth they only exist of micro-organisms (Venkatesan, 2003). The process also slows down with depth, meaning that even at small depths differences can already be observed (Head, 2004).

2.4.2 Biofouling

Biofouling is the generally used term for the spontaneous "unwanted" growth which develops on all kinds of surfaces under water.

It is important to mention that the biofilm and certain algae still form a soft growth. Once acorn barnacles and other shells or tubular organisms are settling, it is called a tough layer of biofouling. This one is the best known and it has also the most baleful influence on the moving efficiency of a ship (Stanczak, 2004).

It is known that a biofilm results in increased corrosion when it appears immediately on metal surfaces. For this reason metal surfaces are treated to prevent corrosion. On these treated surfaces a biofilm will form after a while. When this film, soft or hard, starts becoming a hindrance, one speaks of biofouling.

3. *ECOSPEED AND BIOFOULING*

3.1 *STATUS*

Based on some under water inspections it appears that also with application of the hard Ecospeed coating a certain growth is still possible after a certain time span. This is somewhat to be expected with a hard coating where no toxic substances have been added to avoid biofouling. However, it seems that the growth is limited as long as the ship is in motion since less growth appears at the smooth surface of a ship in motion.

3.2 *RISK EVALUATION ON THE SPREAD OF SPECIES*

Concerning the development of a biofilm, it is mostly about general, almost universal organisms. In any case, no micro-organisms were documented that were transported elsewhere by ships and subsequently have settled themselves permanently, not considering the cholerabacil (*Vibrio cholera* that is supposed to be spread by means of ballast water). However, since marine biology gets more attention the last few years these views will probably need to be adjusted, also because unknown species are still found in the deeper water (cf. Meyers, 2000; Callow, 2002).

The development of a slimy biofilm is thus considered as a very minor risk for spread of alien species.

However, it needs to be mentioned that the risk increases as soon as macro-organisms are colonizing the biofilm. The risk strongly depends on the fact if the macro-algae or the macrozoa are cosmopolitan species or not.

The evaluation of this risk would imply, firstly a profound knowledge of marine biology for the one who performs hull inspections, secondly an easy access to the submerged hull.

When a quite well developed biofilm is detected during an inspection, one will have to decide to proceed with the removal of the biofilm. This can be done by means of an underwater treatment of the hull under high pressure or with brushes, for instance.

When this underwater cleaning is done in time, the risk for the introduction of organisms from foreign areas will be negligible; on the one hand because the soft biofilm contains very cosmopolitan organisms, on the other hand because the organisms will often partially die off by the treatment, and will often fall in a very unfavourable environment (bottom of the ship's dock). The bottom of the dock is often occupied with sediment eating or filter feeding organisms that will use the remainder of the biofilm as temporary food supply on the bottom of the dock (Turner; 2004; Siferd, 2001) .

Most sedentary organisms can only settle to a fixed substrate in a particular phase of their development. This mobile phase is often very short and often requires specific conditions. This means that only when these phases of development are present in a biofouling, these organisms could spread in the environment. These phases nearly always correspond with the presence of full grown species that can spread in a vegetative or sexual way. Through a timely underwater cleaning of the hull, this phase can be prevented, and this should offer a sufficient guarantee against mobile phases of these organisms.

Experiences with Ecospeed clearly show that there is hardly any growth during sailing. After a period of mooring, the growth can develop to a significant extent ([1]). If the first indications of a further advanced colonization are observed (for instance a beginning development of sea acorn) hull cleaning is required. Preferably, this is done before the ship leaves the harbour. Thus, the possible present biofouling is prevented to develop to an active reproduction stage. In other words, a timely cleaning can prevent the biofouling in development from spreading in the next harbour or underway to the next stop of the ship.

3.3 *GLOBAL RISK ASSESSMENT*

To date, the majority of the ships is provided with a layer of paint that has antifouling characteristics by the release of a chemical that prevents biofouling. This is a common practise that has already been used for several decades. However, we have to conclude that organisms were still spread in the 70s and 80s, some of them were clearly identified as "hull hitchhikers". These antifoulings were thus not completely efficient.

Most of the antifouling paints that are used have a negative impact on the marine life because they release biocides. Underwater cleaning is a source of elevated emission of the paint related biocides, because together with the biofilm a layer of paint is released. Due to this cleaning, especially in harbours, often very high concentrations of these biocide chemicals are/were found in the water and sediments with often a negative influence on the regular underwater life as a consequence.

Underwater cleaning was often seen as a source of forced migration of organisms that were loosened from the ship's hull and were thus obliged to find a new habitat (Galil, 2005; Zenetos, 2005). In other words, a well developed antifouling population increases the risk for spread of "hitchhiking" organisms (aliens?) that are able to develop in a new environment.

Port authorities are now sceptic to cancel the prohibition of underwater cleaning for non-toxic paints due to an elevated concern for the introduction of alien species.

[1] The velocity of growth depends on the temperature of the water. Thus, in tropical seas, biofilms develop much faster than in colder regions. Depending on the local situation, the period for loading and unloading will determine if a sufficient growth can be expected or not. In our harbours, a normal loading/unloading cycle will not take that long time to allow the development of a thick biofilm.

The biofilm released during the underwater cleaning certainly contains a volume of living organisms after the film has been removed from the ship's hull. By means of pressure and possibly local heat, part of the organisms from the biofilm will die off, the remainder will gradually sink to the bottom of the harbour's dock and die off or merge with the present micro-flora. The latter is only possible if the local environmental conditions might allow this. A lot of these biofilm fragments will serve as food for the local benthic animals even before they can reach the bottom.

After the application, a hard coating has a more limited impact on the environment than a conventional coating. Critical for the aspect "biofouling" on hard coatings is that the biofilm is removed timely. A regular maintenance scheme depending on the water type and the usage frequency of the ship (tropical waters versus cold waters, fast sailing ships, ships that are moored during long time periods,…) is essential. Alternatively, a "hull monitoring program" could be elaborated defining at which moment underwater inspections are executed. During these underwater inspections a diver equipped with a videosystem or a Remotely Operated Vehicle (ROV) needs to evaluate the biofilm.

An early underwater cleaning also allows to prevent the "stowaways", that are now often found at places of ships with difficult access, such as grids and openings in the hull (Anonymus, 2007). These places are still responsible for the transportation of organisms. Indeed, if hull cleaning is performed regularly, these places can also be treated, so the ship hull can be completely released from biofilm.

From economical considerations dry docking is not desirable. The underwater cleaning of ships with hard coatings is thus important as to justify the environmental benefits economically. The regular use of underwater cleaning is essential to remove the growth in time. In that case, the risk of spread of alien species will certainly not be higher than the spread associated with the conventional used coating systems. However, the hard coatings will not release emissions damaging the environment. Other possible environmental benefits (a reduced fuel usage as a consequence of a reduced water resistance, no repeated application is needed,…) probably generate other environmental and economical benefits. However, these aspects constitute a different task within the Life-project ("fuel consumption monitoring" and "emission reports", performed together with the other Life partners VITO and Antwerp Maritime Academy) to assess the overall environmental impacts associated with the Ecospeed coating.

The literature has shown that the coatings applied in the past have not prevented alien species from travelling to other areas. The first results with hard coatings do not show an elevation of the migration risk of alien species when the risk is compared with the migration risk associated with the paints used until present. Since underwater cleaning is an important part in the usage of hard coatings and the prevention of the development of biofouling, the permission for underwater cleaning of ships treated with these kinds of coatings seems to be essential to be able to fully benefit from the indirect environmental advantages of the hard coatings.

3.4 CONCLUSION

Literature research indicates that a regular removal of a biofilm implies no demonstrable risks for the spread of alien species as long as this happens before mobile spores are formed by the organisms constituting the biofilm. A proper inspection is therefore required.

The developing biofilm constists mainly of micro-organisms. Until present, no studies documenting the introduction of alien species by this kind of biofilm are known. Only for the cholerabacil, transportation by ship is documented. Probably, this cholerabacil is spread by infected ballast water.

A frequent check and cleaning of the coated parts of the ship offers the benefit that the hidden places can be cleaned as well. It seems that these kind of places often carry fully grown biofouling organisms and therefore form a reservoir for colonization of new environments by the present organisms.

The literature has not put forward any argument that indicates that viable alien macro-organisms could still be spread to foreign regions if ship hulls are timely cleaned underwater. Moreover, a regular monitoring of the biofouling contains an additional guarantee that no fully-grown alien organisms are present at the coated underwater parts, so the risk for the development of viable migration stages is almost impossible compared to the conventional coatings used until today.

4. *BIBLIOGRAPHY*

ANONYMUS, 2007, Assessment of introduced marine pest. Risk associated with niche areas in commercial shipping. Final report. Australian Shipowners Association

BEAUONT A.R. et al., 1989, Sandy-substrate microcosm studies on tributyl tin (TBT) toxicity to marine organisms, in Topics in Marine Biology:Proceedings of the 22nd European Marine Biology Symposium, Barcelona, pp 737-743

BOTT T. & Miller, PC. 1983. Mechanisms of Biofilm Formation on Aluminum Tubes. J. Chem. Technol. Biotechnol. 33B, (3), 177-184

CALLOW M.E., 2002, Marine biofouling: a sticky problem, Biologist 49 (1)

CALLOW M.E. et al., 2001, Brefeldin A affects adhesion of zoopores of the green ala Enteromorpha, J. Exp. Bot. 52(360):1409-1415

DE FELICE R.C., 1999, Fouling marine invertebrates on the hull of the USS Machinist in Pearl Harbor prior to its move to Apra Harbor, Guam. Report submitted to U.S. Fish and Wildlife Service.

DIGGINS, TP; Baier, RE; Meyer, AE; Forsberg, RL. 2002. Potential for Selective, Controlled Biofouling by Dreissena Species to Intercept Pollutants from Industrial Effluents. Biofouling vol. 18, no. 1, pp. 29-36

DOBREVSKY I. et al. , 2000. A method of biofilm monitoring in the recirculating cooling water system of a petroleum refinery plant. European Federation of Corrosion Publications (UK), vol. 29, pp. 202-212

FAILLE C. et al., 1999. Cleanability of stainless steel surfaces soiled by Bacillus thuringiensis spores under various flow conditions. Biofouling vol. 14, no. 2, pp. 143-151

GALIL B, 2005, PORT surveys of Alien organisms introduced by ships, National Institute of Oceanography, Israel Oceanographic and Limnological Research, Haifa, Israel

GOMEZ DE SARAVIA, SG; Guiamet, PS; Videla, HA. 2001. Preventing biocorrosion without damaging the environment. Four innovative strategies. Institute of Corrosion, Corrosion Odyssey pp. 9

GRINWIS G.C.M., 2006, Health effects of some aquatic pollutants in European flounder. Laboratory experiments with emphasis on histopathological and immunological aspects, PhD Thesis, Iniversiteit Utrecht, The Netherlands.

HEAD R., 2004, The effect of depth on the accrual of marine biofilms on glass. Biofouling, 20:177-180

HEWITT CL & HAYES, 2002, Risk assessment of marine biological invasions. In Leppäkoski E, Gollasch S, Olenin S (eds), Invasive Aquatic Species of Europe. Distribution, Impacts and Management, Kluwer Academic Publishers, Dordrecht: pp. 456–466.

HILLIARD R. 2005 Best Practice for the Management of Introduced Marine Pests - A Review. publisher GISP

HOLLAND R. et al., 2004, Adhesion and motility of fouling diatoms on a silicon elastomer, Biofouling 20 (6): 323-329

HOLMSTROEM, C; Egan, S; Franks, A; McCloy, S; Kjelleberg, S. 2002. Antifouling activities expressed by marine surface associated Pseudoalteromonas species. FEMS Microbiology Ecology Vol. 41, no. 1, pp. 47-58

KEM, WR; Soti, F; Rittschof, DAF. 2003. Inhibition of barnacle larval settlement and crustacean toxicity of some hoplonemertine pyridyl alkaloids.

Biomolecular Engineering Vol. 20, no. 4-6, pp. 355-361 KERCKHOFS F. et al., 2007, Alien species in the marine and brackish ecosystem: the situation in Belgian waters, Aquatic invasions é(3):243-257

LEE J-W. et al., 2008, Bacterial communities in the initial stage of marine biofilm formation on artificial surfaces, J. Microb. 46: 174-182.

MEYERS S., 2000, Developments in aquatic microbiology, Int. Microbiol 3:203-211

NEHRING S., 2005, International shipping – a risk for aquatic biodiversity in Germany, In: Nentwig W et al., Biological Invasion – from ecology to control, NEOBIORA 6: 125-143

O'CONNORA, N. et al, 1998, Attachment of barnacle (Balanus amphitrite Darwin) larvae: responses to bacterial films and extracellular materials , J. of Exp. Marine Biology and Ecology, Volume 226, Issue 1: 115-129

PANCUCCI M.A. et al., 2005, Update of marine alien species in Hellenic waters, Medit. Mar. Sci, 6/2:1-11

RAMSAY D.B., Dickinson G.H., Orihuela B, Rittschof D., Wahl K.J.,2008.Base plate mechanics of the barnacle Balanus amphitrite (=Amphibalanus amphitrite), Biofouling, 24(2):109-18.

REINHARDT F. et al., 2003, Economic impact of the spread of alien species in Germany; Environmental research, report 201 86 211

ROSENTAHL H., Interactions between coastal resource users: aquaculture, shipping and coastal urban development and their influence on changes in biodiversity

RUIZ GM & JT CARLTON (2003) Invasive Species Vectors and Management Strategies. Island Press, Washington, District of Columbia, USA.

SCOTT L.S., 2001, Hull fouling of Maritime Vessels as a pathway for maritime species invasions to the Hawaiian Islands.

QCHAFFELKE B. et al., 2006; Introduced macroalgae – a growing concern, Journal of Applied Phycology,

SCHULTZ M.P. et al., 2003, Three models to relate detachment of low form fouling at laboratory and ship scale, Biofouling 19-supplement:17-26

SIFERD T.D., 2001, Sachs harbour Benthic Community Survey Summary of Results 1999-2000, Fisheries and Oceans Canada

SIMBERLOFF D. & M. Alexander, 1998, "Assessing Risks to Ecological Systems from Biological Introductions (excluding genetically modified organisms)." In P. Calow, ed., Handbook of Environmental Risk Assessment and Management. Oxford: Blackwell.

SIMBERLOFF D. & B. Von Holle, 1999, "Positive Interactions of Nonindigenous Species: Invasional Meltdown?" Biological Invasions 1(1): 21–32.

STANCZAK M., 2004. Biofouling: It's Not Just Barnacles Anymore, http://www.csa.com/discoveryguides/biofoul/overview.php

TURNER S. & Catere N., 2004, Regional estuary monitoring programme: Benthic macrofauna communities, April 2001 to April 2002: Southern Firth of Thames and Whaingaroa (Raglan) Harbour , Report: TR 2004/08

VAN PASSEN K. et al., Development of an integrated approach for the removal of tributyltin (TBT) from waterways and harbors: Prevention, treatment and reuse of TBT contaminated sediments, Life02/E?V/B/000341

TAKATA L. et al., 2006, Commercial vessel fouling in California: analysis, evaluation, and recommendations to reduce nonindegenous species release from the non-ballast water vector, Produced for the California State Legislature

VENKATESAN R., et al., 2003; Biofilm formation on structural materials in deep sea environments, Ind. J. eng. & mat. Sc.: 10: 486 -491

VERITAS, 2002, Report on the applications of FSA techniques to cover intermodal transportation, transportation systems and related infrastructure; Project funded by the European Community under the 'Competitive and Sustainable Growth' Programme (1998-2002)

WHITMAN, W., Isolation and characterization of a marine methanogenic bacterium from the biofilm of a shiphull in Los Angeles Harbor. Curr. Microbiol. 25: 157-164

WESTING VAN E.P.M. & Ferrari G.M.,2001. Evaluatie van alternatieven voor aangroeiwering op het onderwatergedeelte van recreatievaartuigen, TNO rapport CN96.9934

ZENETOS A., et al., 2005, Annotated list of marine alien species in the Mediterranean with records of the worst invasive species, Mediterranean Marine Science, Volume 6/2: 63-118

E-books

Anonymus, Managing Marine Protected Areas: A TOOLKIT for the Western Indian Ocean; http://www.wiomsa.org/mpatoolkit/Themesheets/K5_ Alien_invasive _species.pdf

BESTEN, P. J. den. Et al, 2005, Ecotoxicological Testing of Marine and Freshwater Ecosystems: Emerging Techniques, Trends, and Strategies. Boca Raton: Taylor & Francis, CRCnetbase EBook Collection

EL-HAWARY, F, ed. The Ocean Engineering Handbook. Boca Raton, Fla.: CRC Press, 2001. CRCnetbase EBook Collection; Location: ONLINE.

KENNISH, M. J., ed. Practical Handbook of Marine Science. 3rd ed. Boca Raton, FL: CRC Press, 2001. CRCnetbase EBook Collection; Location: ONLINE.

MANAHAN, S. E. Environmental Chemistry. 8th ed. Boca Raton, Fla.: CRC Press, 2005. CRCnetbase EBook Collection; Location: ONLINE.

PANKRATZ, T. M. Environmental Engineering Dictionary and Directory. Boca Raton: Lewis, 2001. CRCnetbase EBook Collection; Location: ONLINE.

Websites

http://www.issg.org
www.unep.org
http://www.cabi-bioscience.ch
www.ru.ac.za/
www.hbs.bishopmuseum.org
www.rya.org.uk/KnowledgeBase/environment/Antifouling.htm
www.mcss.sc/MCNEWS/mcn_v2_2_art4.htm
http://www.oceansatlas.com
http://www.csa.com/discoveryguides/biofoul/overview.php
http://www.abc.net.au/rn/science/earth/stories/s24268.htm
http://www.scienceblog.com/community/article1341.html
http://www.babs.unsw.edu.au/about/centres/cmbb_biofouling.html

http://www.erc.montana.edu/
http://www.biosciences.bham.ac.uk/external/biofoulnet
http://www.sgnis.org/index.htm
http://globallast.imo.org/
http://www.bofep.org/alien_species.htm
http://www.iucn.org/dbtw-wpd/edocs/2006-036.pdf
http://www.poseidonsciences.com/antifouling.html

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