Technical Meeting — 2 May 2018

John Lewis, Principal Marine Consultant, ES Link Services, gave a presentation on *Biofouling on Ships: Character, Consequences, Concerns and Control* to a joint meeting with the IMarEST attended by 23 on 2 May in the Harricks Auditorium at Engineers Australia, Chatswood.

Introduction

John began his presentation by asking the question "What *is* biofouling?" and then answering in the following way: Biofouling is "a process of adsorption, colonisation, and development of living and non-living material on an immersed substratum".

The marine world of 10 000 years ago was not characterised (as it is today) by ships, barges, docks, floats, and pilings. Most of the invertebrate species typical of the fouling community are never found elsewhere. Most exist only on substrata where tidal exposure does not occur. In the pre-maritime-human environment, this habitat must have been restricted to natural floating materials, mainly drifting logs, which would have been most abundant in bays and estuaries.

John noted that the fouling of ships' hulls has troubled mankind for centuries. A translation from the Aramaic of a papyrus dated about 412 BCE concerning boat repairs struck an optimistic note: "And the arsenic and sulphur have been well mixed with Chian oil thou broughtest back on thy last voyage and the mixture evenly applied to the vessel's sides that she may speed through the blue waters freely and without impediment".

In the third century, the Greeks were using tar and wax to coat ships' bottoms. In the 13th to 15th centuries, pitch, oil, resin and tallow were in use. The Chinese Admiral, Cheng Ho, had the hulls of his junks coated with lime mixed with poisonous oil to protect the wood from worms. Christopher Columbus was also familiar with the problem: "All ships' bottoms were covered with a mixture of tallow and pitch in the hope of discouraging barnacles and teredo, and every few months a vessel had to be hoved down and graved on some convenient beach".

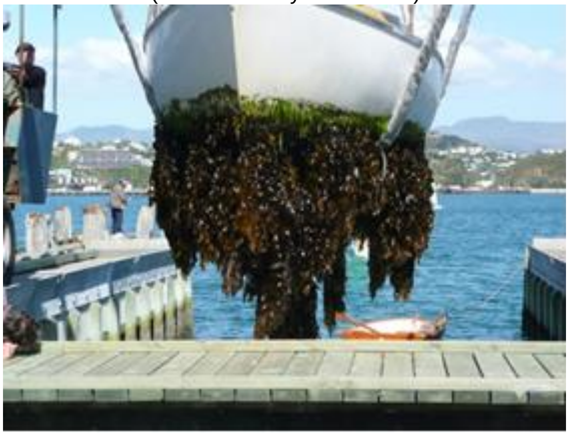
Here John showed a number of photos, including the Battle of Trafalgar, which the British won by way of fouling control—the Spanish vessels all had fouled hulls and so were not so manoeuvrable!

The first application of copper sheeting to the bottom of a vessel was to HMS *Alarm,* and this subsequently became common practice in the Royal Navy fleet. However, with the advent of iron vessels, copper sheeting could no longer be used. From the late 1800s, they used copper oxide in varnishes, and the use of copper oxide in paints continues to the present day.

Here he showed recent photos of fouling, on various locations on ship sides and in sea inlets on different types of vessels.

Fouling on a tug in Cockburn Sound, WA
(Photo courtesy John Lewis)

Fouling in a sea inlet on an OSV in Bass Strait
(Photo courtesy John Lewis)



Fouling on a yacht left too long in the water!
(Photo courtesy John Lewis)

The Fouling Problem for Ships

Fouling presents a number of problems, not the least of which is that the additional drag from the fouling either reduces speed for the same power, or requires additional power to maintain the same speed. The antifouling paint releases biocidal copper ions into the water, and California is trying to ban their use. More fuel means that more greenhouse gases are released into the atmosphere, more CO_2, NOx, SOx and particulate matter. Paint solvents mean that volatile organic compounds are released. Marine pests can be transported in ballast water and biofouling (a whole topic in itself!) And, finally, there are the costs—maintenance, paint replacement, fuel, etc.

What is the Economic Cost of Biofouling?

The antifouling paints and coatings market is projected to grow from USD 5.61 billion in 2015 to 9.22 billion by 2021. The overall cost associated with hull fouling for the US Navy's present coating, cleaning, and fouling level is estimated to be USD 56 million per year for the entire DDG-51 class, or USD 1 billion over 15 years.

In Australia, product sales of boat antifouling for the 2016–17 financial year were reported in the Commonwealth of Australia *Gazette* to be AUD 17 405 749.

The primary cost associated with fouling is due to increased fuel consumption attributable to increased frictional drag.

Antifouling Coating Types

There are basically two types of antifouling coatings: biocidal and non-biocidal.

Biocidal coatings use copper with or without organic biocides, and include the soluble matrix/ablative (where the matrix dissolves at the same rate as the biocide), diffusion/contact leaching/hard (where the biocide diffuses through a hard matrix), and the self-polishing copolymer (where the surface itself polishes away) types.

Non-biocidal coatings include the foul release (where the surface itself reduces the ability of organisms to stick on), mechanically resistant (usually hard epoxies, which have the advantage that they can be scrubbed), and novelty (e.g. fibrous, although none have yet been proven) types.

The International Convention on the Control of Harmful Antifouling Systems on Ships (2001) banned the application or reapplication of all antifouling containing organotins as biocides from 1 January 2003 and required that, from 1 January 2008, ships either not bear such compounds, or bear a coating which forms a barrier to such compounds leaching from underlying non-compliant systems. The convention entered into force in September 2008.

Antifouling biocides need to be

- toxic, yet non-toxic (killing everything!);
- stable, yet unstable;
- broad spectrum, yet not too broad; and
- leachable, but not too fast nor too slow.

Commonly used co-biocides include Diuron, Irgarol, 4,5-dichloro-2-octyl-4-isothiazolin-3-one (DCOIT), zinc pyrithione (ZPT), copper pyrithione (CPT), Dichlofluanid, and Tralopyril.

There are three spheres of regulation for antifouling coatings: the chemical laws, emission laws, and biocide laws. All three of these overlap, and the area in which they *all* overlap is not harmonised, and is the area in which antifouling coatings tend to get caught.

Product Registration

Product registration in Australia is another problem. This is in the hands of the Australian Pesticides and Veterinary Medicines Authority and, when first given this responsibility, they knew nothing about antifouling. It can take up to eight years to have a new biocide approved and, for new paints containing approved biocides, approval can take up to two years. Barnaby Joyce's decision to move the APVMA from Canberra to Armidale has added further delays to approvals due to the large number of experienced staff not making the move. A current case due for approval in October 2017 is unlikely to be signed off until late June 2018, despite required risk assessments having being completed!

Australia has only 53 antifouling products approved for use; countries overseas have hundreds. Here John showed some charts which indicated the rate of approvals in Australia, which vary from none to a high of seven in one year, but typically between one and four. More than half of the registered products were first registered more than 10 years ago, and 11 more than 20 years ago.

New Biocides

New biocides on the market include

- Econea (tralopyril), developed by Janssen PMP, and is metal free and ten times more active than copper. It can be used with a copper biocide to reduce the coper content. It is supported under EU Biocidal Products Regulation, and is US EPA approved. It is already used in Sherwin-Williams Seavoyage Copper-free, International Interspeed 5640, West Marine CFA Eco, and International Pacifica Plus antifouling paints.
- Selektope (metadomidine), developed by I-Tech in Sweden, and has a pharmacological mode of action to combat barnacle settlement. It temporarily stimulates the octopamine receptor in the barnacle larvae, and the larvae are repelled. I-Tech has a supply agreement with Chugoku Marine Paints. Selektope is endorsed by the EU Standing Committee on Biocidal Products and EU-wide approval was granted on 1 January 2016.

However, it could be ten years before products containing these biocides are approved for use in Australia.

Antifouling Options

The effective life of antifouling coatings is as follows:

Copper-based conventional	12–24 months
Copper-based erodible	36 months
Copper-based SPC	60 months
Biocide-free fouling-release	>60 months
Novel technologies	unproven

However, as the effective life increases, so too does the cost.

Air Emissions

The latest information has international shipping contributing approximately 2.7% of global carbon emissions. Even considering the effects of the global financial crisis, the predicted growth in global trade and the likely future emissions reduction from land-based industries means that, in real terms, the industry's percentage contribution is likely to significantly increase.

The *Third IMO Greenhouse Gas Study 2014* found that the average annual fuel consumption (2007–12) by all ships was between 247 and 325 Mt.

Another study in 2011 found that increasing fouling from FR-0 (a hydraulically smooth surface) to FR-30 (with heavy slime) increased fuel consumption by 10.3%

Ship Energy Efficiency Management Plan

The International Maritime Organisation has developed the Ship Energy Efficiency Management Plan (SEEMP) to help ship operators meet the Energy Efficiency Design Index requirements (EEDI). The SEEMP is a ship-specific plan which can be efficiently implemented on vessels by planning, implementation, monitoring and self-evaluation and improvement.

The other focussed area of SEEMP is to reduce GHG emission while increasing operational efficiency of the ship, resulting in less fuel consumption. Steps to achieve efficient operation of the ship under SEEMP include speed optimization, weather routing, hull monitoring and maintenance, efficient cargo operation, and electric power management.

SEEMP is basically monitoring, carried out by shore staff who collect the data from the ship through engine-room log books, other ship records, and documentation. SEEMPs can include planning for annual in-water hull cleaning to minimise hull resistance.

Impacts of Invasive Species and the BWM Convention

There are estimated to be 500 alien marine species within the coastal waters of the USA (around 200 of these are in the waters of San Francisco Bay alone). Worldwide, the number is far higher. Why does this matter? Why should we be worried about it, when many intentionally-introduced alien species provide us with food, recreation or jobs?

That answer is that, while many species which are introduced into a new environment do no harm, many others have significant ecological, economic and human-health impacts. Invasive seaweeds are claimed to have smothered seabeds, invasive crabs to roam the sea floor eating everything in their path, invasive jellyfish leading to the collapse of fisheries and people having been killed by pathogens carried around in ballast water. Sometimes the impacts are quick and dramatic but, more often, they are indirect and subtle, and may escape notice for some time.

On 8 September 20-17 IMO's Ballast Water Management (BWM) Convention entered into force. This is a global treaty focussing on better management of invasive aquatic species and healthier marine ecosystems.

Invasive vs Non-indigenous Species

We must be careful to distinguish between "invasive" and "non-indigenous". Invasive species cause harm (of one form or another), and are a subset of all non-indigenous species, of which most are not harmful.

Ships have been identified as the single most-important vector for the dispersal of non-indigenous marine species around the world. On an international ship, every fouling species is a non-indigenous species on that artificially-created, newly-formed, mobile island. Jurisdictional definitions of non-indigenous species are artificial.

IMO Resolution MEPC.207(62)

IMO Resolution MEPC.207(62) *Guidelines for the Control and Management of Ships' Biofouling to Minimise Transfer of Invasive Aquatic Species* was adopted on 25 July 2011 and provide a globally-consistent approach to the management of biofouling on ships. The *Guidelines* give recommendations on general measures to be considered in order to reduce the risk of transfer of biofouling on ships not only in relation to the aspects of choosing the right fouling control paint for the different parts of the ship but also to give consideration to ship design, dry dock maintenance, recycling , crew training etc.

The *Guidelines* encompass

- Biofouling management plan and record book.
- Antifouling installation and maintenance.
- In-water inspection, cleaning and maintenance.
- Design and construction.

IMarEST/IPPIC Template

The IMarEST together with the International Paint and Printing Ink Council in 2017 published the document *Template for a Biofouling Management Plan*. Whilst the IMO *Guidance* detailed the information which is important to be recorded regarding fouling control, no formal template was provided in which to capture that information. The new document provides such a template to capture all relevant information prescribed in the IMO guidance, with particular attention to coatings.

The template encompasses

- The choice of anti-fouling system (AFS) for the external hull, with a check list system to inform this choice.
- Selection of the AFS for niche areas where hydrodynamic conditions may differ from those found on the external hull.
- Planned management actions to be completed between planned dry dockings to minimise the biofouling on the hull.

However, it is ultimately the ship owner's or operator's decision to have and to maintain a biofouling management plan and biofouling record book on board their ship.

NZ Craft Risk Management Standard for Biofouling

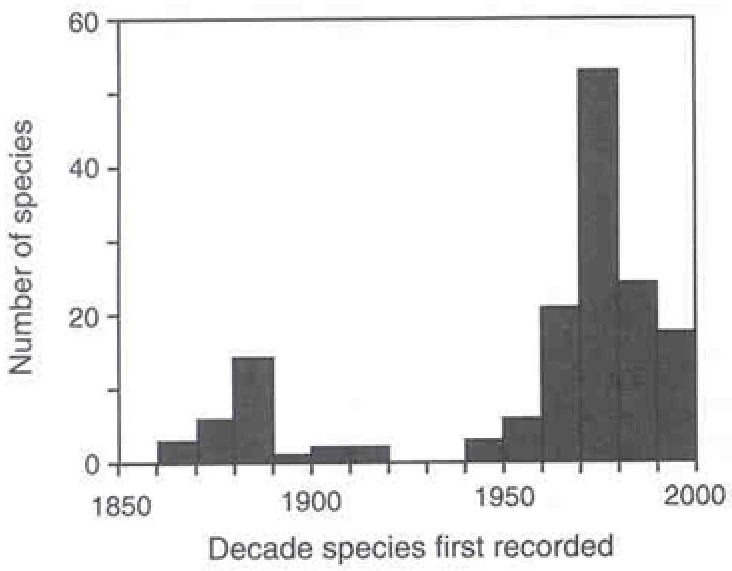
New Zealand's Craft Risk Management Standard came into effect on 15 March 2018, applies to all vessels arriving in New Zealand, and specifies the requirements for the management of biofouling risk associated with vessels entering New Zealand's territorial waters. The basic requirement is that all arriving vessels are "clean" below the waterline on arrival, with thresholds being governed by the vessel's itinerary

Short-stay vessels are in NZ waters for 20 days or less and only visit approved ports of first arrival. On entry to NZ waters, these vessels are allowed a slime layer, gooseneck barnacles, and slight fouling of early-stage biofoulers, e.g. barnacles, tubeworms or bryozoans.

Long-stay vessels are in NZ waters for 21 days or more and/or visit an area not approved as a port of first arrival. On entry to NZ waters, these vessels are allowed a slime layer and gooseneck barnacles, but no other fouling.

Marine Species in Australia

Non-invasive marine species are not new, as introduced species were first recorded in Port Phillip Bay in 1860.



Distribution by decade of the first records of introduced and crypogenic species in Port Phillip Bay
(Chart courtesy John Lewis)

However, there have been more than 200 years of maritime transport into Australia. In 2012–13 there were close to 30 000 commercial vessel calls to Australian ports, plus the many yachts and fishing, non-trading and defence vessels. About eleven species have been introduced that have established and, arguably, caused significant impacts. Only three of these species are considered likely to have been introduced in biofouling. The species include

- Dry ballast — Carcinus maenas (European green crab)
- Aquaculture—intentional — Crassostrea gigas (Pacific oyster)
- Aquaculture—accidental — Codium fragile spp. fragile (green sea fingers), Grateloupia turuturu (devil's tongue weed), and Maoriculpus roseus (New Zealand screw shell)
- Aquarium trade — Caulerpa taxifolia (killer algae)
- Ballast water — Asterias amurensis (Northern Pacific seastar), Corbula gibba (European basket clam), and toxic dinoflagellates
- Biofouling — Arcuatula senhousia (Asian date mussel), Sabella spallanzanii (Mediterranean fanworm), and Undaria pinnatifida (Japanese kelp)

Ship Biofouling

Over history, vessel hulls have been colonised by biofouling species that have the opportunistic traits and environmental tolerances to survive on these artificial habitats.

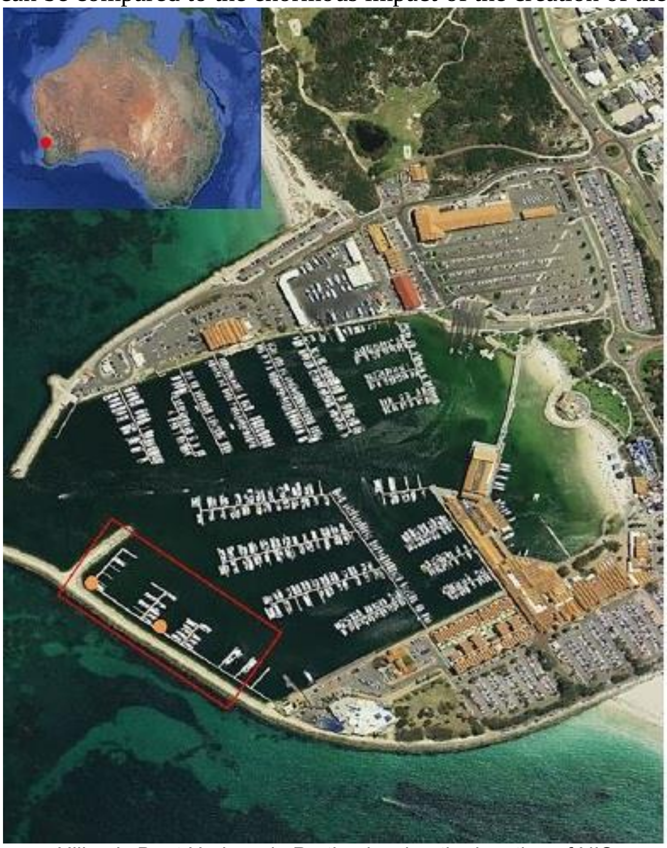
The speciose biofouling community which has evolved through the maritime era has been distributed into disturbed and artificial environments worldwide, and these species contribute to the majority of alien marine species found in any country, in their harbours and marinas, and on their vessels and maritime infrastructure. On an international ship, every fouling species is a non-indigenous species as the ship is a newly-created mobile island.

Most fouling vectored alien marine species which colonise new regions do not cause significant environmental, economic, human health or social impact, except as a contribution to the overall biofouling impact on vessel performance, mariculture infrastructure, coastal industrial plants, etc.

Ecological Impact

Marine biofouling by non-indigenous species is almost completely confined to artificial surfaces and structures and/or disturbed environments. Establishment of biofouling non-indigenous species is a secondary impact.

Here John showed an aerial view of Hillary's Boat Harbour in Perth, which is totally artificial harbour. The area in which non-indigenous species were found is confined to the inside of the seaward breakwater (outlined in red in the diagram), and this can be compared to the enormous impact of the creation of the harbour itself!



Hillary's Boat Harbour in Perth, showing the location of NIS
(Photo courtesy John Lewis)

Domestic Biofouling Species Spread

Here John showed a slide of the spread of Undaria pinnatifida (Japanese kelp) in Port Phillip Bay. After its first recording at Point Wilson in 1996, it was first detected in the Port of Melbourne in 1999, then progressively spread to Point Cook in the west, and Beaumaris in the south-east. Subsequent discoveries in Geelong (2007), Blairgowrie (2007), Portarlington (2008) and Queenscliff (2012), and outside the heads at Apollo Bay in 2009 (approximately 96 km south-west of the heads, and 154 km from St Kilda!), are all on piers or harbour structures and linked to movements of small craft.

In-water Cleaning of Ships' Hulls

The Australia and New Zealand Environment Consultative Council (ANZECC) published a *Code of Practice for Antifouling and In-water Hull Cleaning and Maintenance* in 1997. Under this code, no part of a vessel's hull treated with an antifouling coating was to be cleaned in Australian waters. In-water hull cleaning was prohibited, except under extra ordinary circumstances and permission not normally granted. The cleaning of sea

chests, sea suction grids and other hull apertures could be permitted, provided that any debris removed is not allowed to pass into the water column or fall to the sea bed. The polishing of ship's propellers could also be permitted, subject to any conditions attached to the permit.
The advantages of in-water cleaning include

- biosecurity;
- fuel savings;
- lower CO_2 emissions;
- corrosion control;
- extension of paint service life;
- cost vs. dry docking; and
- availability vs. dry docking

The disadvantages include

- biosecurity; and
- chemical contamination.

Australia's Standing Council on Primary Industries endorsed a new publication, *Antifouling and In-water Cleaning Guidelines,* on 26 June 2013. These *Guidelines* replace the ANZECC *Code of Practice for Antifouling and In-water Hull Cleaning and Maintenance* and permit in-water cleaning if the growth has accumulated locally or, if accumulated elsewhere, by using equipment that captures the biological waste.

Technology Gaps
One of the gaps in our technology is a knowledge of good practice for sea inlet design. Most designs allow for an accumulation of biofouling that does not impede water flow, rather than minimisation of biofouling. A recent study by the RMIT University investigated the flow of water through sea inlets according to their shapes. In a typical box-shaped inlet, there was a lot of circulation and large inconsistent regions of low wall shear. This meant that the antifouling coating can't work efficiently, and the wear rate is hard to predict. RMIT then designed a number of alternative shapes, and the shape with the best performance turned out to be almost conical, from the square base at the hull side to the circular entry to the ship's pipework. With this design, there were virtually no dead spots, minimal circulation, and a very uniform and predictable shear distribution.

Marine Growth Prevention Systems
Marine growth prevention systems are installed to prevent biofouling clogging seawater pipework. Methods include

- Direct chemical dosing, using sodium hypochlorite or an "antifouling" solution.
- Electrochemical dosing, using copper (or aluminium) anodes.
- Others, such as ultrasound.

The efficacy of various marine growth prevention systems has not been conclusively demonstrated.

IMarEST Special Interest Groups
IMarEST Special Interest Groups (SIGs) are voluntary groups which operate to the benefit of a specialist field. SIGs are governed by a committee of members but all SIGs are open for all members to participate in as corresponding members.
SIGs are developed to act as an enabler for the creation, transfer and sharing of knowledge. They utilise 'Nexus', the IMarEST's members-only collaboration and networking platform, enabling SIG members to discuss technical topics and to address conflicts and synergies within sectors. SIGs act as a portal for members and organisations seeking to improve their knowledge about the large variety of disciplines within the marine sector.
Special interest groups aim to:

- Advance the expertise and status of members working in the field, and to provide help and advice to expand their knowledge of the subject.
- Act as a clearinghouse for up-to-date, relevant information and make it available to members.
- Maintain and expand a network of members and affiliate organisations working in that area or who are simply interested in keeping up-to-date.
- Develop conferences, seminars, and other events related to specialist issues.
- Produce information and position papers on related topics.

- Provide impartial, timely and technically sound information to governments and Intergovernmental Organisations.
- Provide expertise and advice to those in the early stages of their careers.

IMarEST has 20 special interest groups, and one of these is the Ballast Water Management SIG.

Biofouling Management Expert Group

The Biofouling Management Expert Group (BMEG) was formed as a key output of the inaugural, IMarEST-supported ANZPAC Workshop on Biofouling Management for Sustainable Shipping which was held in Melbourne in 2013. This expert group aims to establish a platform for a united way forward on the key international issue of marine biofouling management, and is chaired by John.

Key issues include

- Effective and practical biofouling management measures;
- Biofouling management guidelines, requirements and regulations: present and future;
- In-water cleaning of ships' hulls: costs, benefits, impacts and regulation;
- regulation and scrutiny of new and existing fouling control coatings and antifouling biocides;
- costs and impacts of biofouling: ship energy efficiency and harmful aquatic species transfer; and
- ship biofouling management: best practice guidance.

Conclusion

Biofouling on ships is a problem, and has been with us for a long time. We need to focus our resources for greatest benefit, and identify the significant impacts: whether it is biofouling per se, or species specific. We need to determine effective management strategies to address identified risks as identified in the IMO *Biofouling Guidelines* and Australia's *Antifouling and In-water Cleaning Guidelines*, and risks associated with fuel consumption, domestic spread, improved antifouling technology, paints, and sea inlet design.

Questions

Question time was lengthy and elicited some further interesting points.

Marine growth in sea inlets can be checked by blasting steam through the sea inlets, say once per month, provided that the vessel has steam-generating capability on board. There has been a lot of work done on what level of temperature is required to kill various organisms, and it certainly needs to be an elevated temperature.

The Oberon-class submarines [*remember them?*—Ed.] used to pick up tubeworms in their sea inlets when berthed at Neutral Bay. They would then go to Singapore (for example) where the higher water temperature led to rapid growth of the tubeworms, and they would require an emergency docking to clear their sea inlets! Conversely, the Anzac-class frigates picked up mussels in port and then, going south into colder water would lead to the death of the mussels, and the clogging of pipework with empty mussel shells.

An interesting feature of the construction of the Anzac-class frigates at Williamstown occurred during the fitting-out phase, with the ship berthed alongside a wharf. While the ship gradually accumulated fouling over most of the hull, nothing fouled *above* the zinc anodes. They worked out that the zinc anodes were interacting with the impressed-current cathodic protection system on the wharf, and were releasing bubbles of gas which ran up the hull and prevented marine growth.

Does ultrasonic hull cleaning work? John has done some testing, and has found that acoustic vibration can stop barnacles from settling. The larva cones onto the hull, and moves around looking for a place to settle. If nowhere favourable is found, e.g. due to acoustic vibration, then the larva moves off to find somewhere more to its liking. More generally he has seen no evidence that commercial systems work.

The vote of thanks was proposed, and the certificate and "thank you" bottle of wine presented, by Bill Bixley.

The vote was carried with acclamation.