Hull fouling & in-water cleaning: Risks and updates

Dr Eugene Georgiades et al.
Biosecurity Risk Analysis (Animals and Aquatic)
Existential prologue

Image: CSIRO Australia
Presentation overview

• Context setting
• New Zealand’s biofouling standard
• In-water cleaning
• Australian and New Zealand Guidelines
• New Zealand research
• International updates
• Acknowledgements
New Zealand’s marine values

- **Environment**
  - Marine biodiversity hotspot
  - Marine species estimated to make up 80% of all NZ native species
  - 51% of NZ marine species are endemic

- **Economic**
  - Marine aquaculture ~ $500 million annually
  - Commercial fishing > $1.3 billion annually (70% deep water)

- **Social/Recreation**
  - Majority of population live within 50 km of coast

- **Culture**
  - Ocean integral to Māori culture and identity
Disease spread associated with biofouling
- Ostreid herpesvirus microvariant 1
- Bonamia ostreae
- Marteilioides chungmuensis
New Zealand vessel arrivals

- > 3,000 vessels enter annually
  - 70% merchant vessels
  - 20% recreational vessels
  - 3% fishing vessels
  - 3% passenger vessels
  - other
  (New Zealand Customs Service 2008)

- Nature of the risk
  for each vessel type unknown
New Zealand Government commissioned research

- Objectives
  - Identity, origin and extent of biofouling
  - Relationship between presence of non-indigenous species (NIS) and biofouling extent
  - Factors that influence the presence of NIS and biofouling extent

Image: Diving Services NZ Ltd
New Zealand Government commissioned research

• Results
  – 72% of vessels fouled
  – NIS ~ 60% of vessels
  – NIS not established in New Zealand on 1/3 of these
  – Clean vessels
    – 35% merchant vessels
    – 33% passenger vessels
    – 27% fishing vessels
    – 16% recreational vessels
New Zealand Government commissioned research

• Summary
  – All major vessel types likely to be fouled
  – Common fouling species
    – Barnacles
    – Bryozoans
    – Tubeworms
    – Macroalgae
    – Bivalves
  – Niche areas – abundant and diverse fouling

More biofouling = higher likelihood of NIS

Image: Diving Services NZ Ltd

Inglis et al. 2010
Risk Analysis

• Hazard Identification
  – > 2000 species associated with vessel hulls
  – 20 broad taxonomic groups
    – Based on trait similarities

• Criteria
  – Known components of marine biofouling assemblages
  – Known to be introduced to new locations
  – Known impacts on core values

Biofouling is a risk to NZ values
Cost Benefit Analysis

• Results:
  - Benefits of mandatory action outweigh cost within 10 years
  - Net benefit (50 years) $520 - $865 m
  - Beneficiaries:
    - Aquaculture (90% of benefits)
    - Recreational fishing (3%)
    - Recreational use of beaches (2.7%)
  - Cost:
    - Non-compliant vessels (77- 83%)
    - Freight vessels (95% of above cost)

Image: Diving Services NZ Ltd
Craft Risk Management Standard (CRMS)

- Craft Risk Management Standard for Vessel Biofouling signed off
- 4 year “early adoption period” (voluntary)
- Mandatory regulation to begin May 2018
- Alignment with IMO Guidelines
- Risk minimisation

For more details
- Standard
- Science underpinning standard
Craft Risk Management Standard

• Outcome
  – Minimise the entry of harmful organisms

• Meeting the outcome
  – Arrive with a “clean” hull
  OR
  – Provide evidence of biofouling management
Meeting the CRMS

- **Continual maintenance using best practice**
  - IMO Guidelines
  - Biofouling Management Plan and Record Book

- **Craft Risk Management Plan**
  - MPI approved
  - Reduction of risk equivalent to arriving with “clean” hull

- **Approved Treatments**
  - MPI approved
  - Reduction of risk equivalent to arriving with “clean” hull

- **Clean before/upon entry**
  - Must be carried out within 30 days prior to entry into NZ
  - Or immediately upon arrival
Fouled vessels – what are the options?

- No action
- Provision of educational materials
- Restriction of vessel stay > 24 hr
- Taxonomic identification of fouling
- Restriction of vessel stay ≤ 24 hr
- Direct vessel to subsequent port where approved system is immediately used to clean or treat vessel
- Use of approved system to clean or treat vessel at original recipient port
- Haul-out or dry docking (vessels ≤ 1800 dry weight tonnage)
- Refusal of entry into recipient port

Image: Diving Services NZ Ltd
In-water cleaning – why?

**Advantages**
- Fuel savings
- Lower CO2 emissions
- Corrosion control
- Extend paint service life
- Cost vs. dry docking
- Availability vs. dry docking
- Biosecurity

**Disadvantages**
- Biosecurity
- Chemical contamination

Required 18% less shaft horsepower to achieve 25 knots just from removing slime layer!
New Zealand (and Australia): In-water cleaning

- 1997
  - Code of Practice for Anti-fouling and In-water Hull Cleaning and Maintenance (ANZECC Code).
  - Concerns
    - Establishment of non-indigenous species
    - Release of biocides

- 2009
  - Code reviewed

- 2013 +
  - Guidelines released
  - Re-released 2015
  - Undergoing review 2018

*NO!*

Yes *but*...
New Zealand (and Australia): In-water cleaning

- Guidelines (principles)
  - In-water cleaning
    - Regular is effective
    - Not a substitute for poor practice
    - Suitable anti-fouling coatings only
    - Not suitable on coatings at the end of their service life
- Clean before you leave
- Minimise discharges
New Zealand (and Australia): In-water cleaning
Decision Support Tool

Paint

Fouling

Conditions

Aspirational goal

Context & system
Summary: NZ in-water cleaning research

- 2018
  - Testing in-water cleaning systems (external hull)
- 2017
  - Frameworks for testing in-water cleaning systems (internal areas)
  - Treatment of recreational vessel pipework
- 2015
  - Frameworks for testing in-water cleaning systems (external hull)
- 2013
  - In-water cleaning of vessels: Biosecurity and chemical contamination risks
- 2012
  - Scenarios of vessel biofouling risk and their management
- 2009
  - Review of options for in-water cleaning of ships
- 2008
  - Determining the efficacy of incursion response tools:
    Rotating brush technology (coupled with suction capability)
Balancing the risks of in-water cleaning

• Research question
  – “When do the environmental costs of releasing non-indigenous species and chemical contaminants during in-water cleaning outweigh the risks of no action?”

• Findings
  – Biocide free paints (acceptable)
    • Slime layer
    • Vessels with < 15% fouling (with recapture)
  – Biocidal paints (acceptable but…..)
    • Depends on vessel size, % fouling cover and type

More on this later!
Framework for testing in-water cleaning systems

In-water cleaning technologies – Review of information

Morrisey et al. 2015

Procedures for evaluating in-water systems to remove or treat vessel biofouling

Morrisey & Woods 2015

• Objective
  – Develop standard testing requirements for in-water cleaning systems with respect to biosecurity risk

• Approach
  – Categories
  – Investigation of biosecurity risks
  – Standard setting
  – Test development

NIWA Ltd
ES Link Services Pty Ltd
MPI
We must find the balance between
- minimising biosecurity risk
- practicality of the testing
- scientific robustness
- cost to the developer
Framework for testing in-water cleaning systems

• Categories
  – Mechanical (e.g. brushes, water jets)
  – Manual (e.g. hand tools)
  – Surface treatments (e.g. heat, ultra sound)
  – Shrouding technologies (e.g. encapsulation, enclosure)

Biosecurity risks identified - from set-up to de-mobilisation!
Framework for testing in-water cleaning systems

- Performance standards for testing
  - Manual and mechanical systems
    - Removal of all visible macrofouling
  - Shrouding and surface treatment systems
    - All biofouling rendered non-viable
  - Effluent treatment
    - Maximum particle size (12.5 µm) or
    - Non-viable or
    - Not discharged
Framework for testing in-water cleaning systems

- General test requirements
  - Vessel testing using the full system
  - Simulation of intended use
  - Evaluation conducted by approved, independent contractor
Framework for testing in-water cleaning systems

Factors considered

- System types
  - Mechanical removal
  - Manual removal
  - Surface treatments
  - Shrouding technologies

- Vessel areas (& types)
  - Flat
  - Curved
  - Niche
  - Wind-and-water line
  - Whole vessel

- Fouling types (& cover)
  - Moderate soft
  - Moderate hard
  - Heavy hard

- Paint types
  - Biocidal
  - Non-biocidal

- Environment
  - Current speed
  - Sea conditions
  - Visibility, etc
Framework for testing in-water cleaning systems

Guidance provided on

- Provision of system documentation
  - Mechanism of action
  - Technical specifications
  - Intended application
  - Standard operating procedures

- Testing process
  - Independent oversight
  - Choice of vessels
  - Level of replication
  - Environmental conditions

- Test methods
  - Vessel surfaces / regions
  - Types and level of biofouling
  - Effects on anti-fouling coatings
  - Waste capture and treatment

- Data recording
  - Type
  - Reporting templates

- Rationale
  - Why?
  - Cost
Testing efficacy of in-water cleaning systems

- **Summary**
  - **Framework**
    - Transparent, robust and practical
    - Will inform MPI’s requirements
    - Industry certainty regarding MPI expectations
    - Independent
    - Cross jurisdiction approval
Operation: Sea chest!

• Niche areas
  – Small proportion of the hull
  – High susceptibility to biofouling
  – Increased fouling abundance and diversity relative to hull
  – Reactive measures to mitigate biosecurity risk?

• Research objectives
  – Evaluate reactive methods
  – Develop data requirements for efficacy testing

• Literature review (accepted *Mar. Tech. Soc. J.*)
  – In-water systems to remove or treat biofouling in vessel sea chests and internal pipework

Coming soon!

Abraham Growcott
Dan Kluza
Eugene Georgiades
MPI

www.mpi.govt.nz/document-vault/11821
Treatment of recreational vessel pipework

- Niche areas
  - Often over-looked
  - Knowledge gap regarding treatment

- Research objectives
  - Identify suitable treatment
  - Validate treatment
    - Laboratory testing (mock pipework)
    - Vessel testing
  - Deliver operational protocol for use at the border

ETA = 2017

Image: Diving Services NZ Ltd

Cawthron Institute
NIWA Ltd
Biofouling Solutions Pty Ltd
In-water cleaning in New Zealand

• Ministry for Primary Industries
  – Provides guidance to local authorities (Regional Councils)
  – All cleaning undertaken according to Aus/NZ guidelines

• In-water cleaning regulations
  – Regional Coastal Plans under Resource Management Act
    – Designed and developed by Regional Councils
    – Council approval required
      – Unless already permitted within that area
In-water cleaning - Australia

- **Australian Federal Government**
  - Provides guidance to State/Territory Governments and port authorities
  - All cleaning undertaken according to Aus/NZ guidelines

- **Review of Aus/NZ guidelines 2018**
  - Establish baseline activities
  - Explore barriers to uptake
  - Improvements to cleaning
  - Promoting proactive cleaning (slime layer)
  - Stakeholder identification for permissions
In-water cleaning - Western Australia

2011: WA Dept. Fisheries commissioned research for system development to clean or treat large (> 40 m) vessels

Report 1
In-water hull cleaning and filtration system: In-water cleaning trials
26-28 November 2012

No particles > 12.5 µm observed in effluent

Effluent [Cu] ~ 250 µg/L
45 m vessel = 87.5 g Cu removed
Effluent = 350,000 L
Dilution required to meet ANZECC 90% protection criteria [3 µg/L] = 27,000 L
Fremantle Port = 13 million L
In-water cleaning - Western Australia

- Policy released March 2015
- Out of water treatment is preferred
- Promote “Clean before you leave”
- Prevention – minimise biofouling - accumulation
- By 2020 zero secondary biofouling

In-water cleaning - California

- California State Lands Commission
  - Mandate to manage invasive species
  - In discussions with Regional Water Quality Control Boards

- State Water Resources Control Board
  - Prohibited in copper impaired waters
  - Discharge limit: Long Beach, San Diego & Los Angeles Port ~3.1 µg/L
  - ~16 vessels cleaned per year (> 3 NM from land)

- San Francisco Water Quality Control Board
  - Unimpaired waters
  - Best Management Practices Fact Sheet
In-water cleaning – California (San Francisco)

- **Operational triggers**
  - Discharge water
    - [Copper] should not exceed 100 µg/L
    - [Zinc] should not exceed 700 µg/L
In-water cleaning - Hawaii

- Not permitted in commercial harbours
  - Hawaii Dept of Health and Dept of Transportation
  

- Still occurs
  - Military, commercial, cruise ships, research, fishing and recreational vessels
  - No recapture technology

- Dept of Land and Natural Resources (Biosecurity)
  - Discussions re: Policy and Regulations to allow biosecure cleaning
In-water cleaning – what are we protecting?

- Considerations
  - Biosecurity
  - Chemical contamination
  - In-water cleaning technology

- Approach
  - Act now?

Image: New Zealand Diving and Salvage Ltd

- Potentially permanent & widespread effects
- Short-term local effects
- Rapid improvements
- Wait
Other MPI biofouling-related Operational Research

- Viability PCR
- Treatment of internal pipework of recreational vessels
- Vessel biofouling risk profiling
- Fisheries and aquaculture processing facilities – waste management
- Biofouling and aquatic disease spread
- In-water cleaning – system testing
- Sea chest and internal pipework – system testing
Acknowledgements

- Service providers
  - NIWA Ltd
  - ES Link Services Pty Ltd
  - Cawthron Institute
  - Biofouling Solutions Pty Ltd
- In kind support
  - Dept. of Fisheries Western Australia
  - Australian Dept. of Agriculture and Water Resources
  - California State Lands Commission
  - Dept. Land and Natural Resources, Hawaii
- MPI
  - MPI Operational Research Team!
  - Biosecurity and Environment Group
  - Response Group
  - Long-term Incursion Management Group

Beards on faces NOT on boats!!!

Special thanks!
Lena Granhag
Chalmers University
Gothenburg
Non-indigenous species from hull fouling in Danish marine waters

Dr. Frank Stuer-Lauridsen (Denmark)

- Current status study
- Hot spot identification
- Proposal for programme
- The MONIS4 effort in 2017-2018
Selected Services

**Equipment manufacturers**
IMO and USGC approval development for Ballast Water Treatment Systems

**Authorities and DK EPA**
Ballast water regulation Strategy on monitoring/inspection Hull fouling assessment

**Shipowners and associations**
Risk assessments issues

**IMO**
Consultant on approval of ballast treatment water systems

- Invasive species
- Ship recycling
- Air emissions
- Arctic, Waste, Oil & Gas
Driving forces for NIS


- MS 5. Establish and implement a monitoring programme by 15th July 2014.
- MS 6. Develop a programme of measures by 2015 and operationalize the programme by 2016.
- MS 7. Member States shall by 2020 at the latest take the necessary measures to achieve “Good Environmental Status”.

BWMC and OSPAR/HELCOM

- Monitoring in ports for exemptions under BWMC
- Populate OSPAR/HELCOM NIS database after Joint Harmonised Procedure
The desk top study on hull fouling in 2015 (DNA 2016):

**Do we potentially have a problem?**

**What can we do?**

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*Non-indigenous species from hull fouling in Danish marine waters*

January 2016
Hull fouling and NIS

- What is the status on data in DK?
- Do we have potential hot spots?
  - STS locations
  - Ports of refuge
  - Shipyards
  - In water hull cleaning
  - Marinas
Vectors in general

- Aquaculture: 16%
- Ballast water: 22%
- Hull fouling: 16%
- stocking: 9%
- Ornamental: 2%
- Range expansion: 6%
- Science: 1%
- Bait: 1%
- Not assessable: 1%
- Lessepsian migration*: 24%
- Canal (other than Suez): 2%

Status in Denmark

- Approx. 46 established introduced aquatic species since late 19th century
- Approx. 1 new species every 4 years
- After 1980 approx. 1 new species every 2 years
- Benthic organisms (17) and macroalgae (11)
- Invasive:
  - NEW: Mnemiopsis leidy, Sargassum muticum, Gracilaria vermiculophylla, Pseudochattonella verruculosu, Marenzelleria viridis, Neogobius melanostomus
  - OLD: Mya arenaria, Neanthes succinea

Gollasch, 2006

* Species movement through the Suez Canal

Based on 2012 Note by DCE (Stæhr and Thomsen)
Vectors for NIS in Denmark since 1880

Top 3 Denmark
- Ballast water
- Oysters
- Hulls

Vectors for introduced number of species

- Aquaculture species
- Larvae from aquaculture
- Introduced aquatic plant
- Introduced with eel
- Unknown
- Hull fouling
- Introduced with oysters
- Ballast water

Based on presentation by DCE (Stæhr)
Monitoring and data resources

Existing monitoring, included national database (MADS)
- Phyto/zooplankton, macroalgae, angiosperms, benthic organisms, fish, mammals, seabirds
- Not directed towards NIS and no time series

Compilation of data
- NOBANIS
- HELCOM (Baltic) and OSPAR (North Sea)

Information on vessels
- Automated Information System AIS
- Ports, Port State Control
- Municipality (4-5 have permitted in-water hull cleaning)

From DNA (2016)
Table 1: Compiled list of aquatic NIS imported to Danish marine waters via hull fouling. An "x" signifies inclusion of the species in the list and a "-" signifies that the species is not mentioned. Stæhr and Thomsen (2012) characterised NIS in Danish marine waters and Madsen et al. (2014) compiled background data and reassessed a number of species for a report on the pathways on NIS introduction. The original lists were reduced by only including species described as benthic (sessile) organisms living in marine or brackish waters, or species associated with these organisms.

<table>
<thead>
<tr>
<th>Species</th>
<th>Taxa</th>
<th>Stæhr &amp; Thomsen (2012)</th>
<th>Madsen et al. (2014)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aglaothamnion halliae</td>
<td>Macroalgae</td>
<td>x</td>
<td>-</td>
</tr>
<tr>
<td>Balanus improvisus</td>
<td>Barnacles</td>
<td>x</td>
<td>x</td>
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<td>Bonnemaisonia hamifera</td>
<td>Algae</td>
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<td>x</td>
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<td>Caprella mutica</td>
<td>Crustaceans</td>
<td>-</td>
<td>x</td>
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<td>Codium fragile</td>
<td>Macroalgae</td>
<td>x</td>
<td>-</td>
</tr>
<tr>
<td>Cordylophora caspia</td>
<td>Hydroids</td>
<td>x</td>
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<tr>
<td>Dasya baillouviana</td>
<td>Macroalgae</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Elminius modestus</td>
<td>Barnacles</td>
<td>x</td>
<td>-</td>
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<td>Ficopomatus enigmaticus</td>
<td>Annelids</td>
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<td>Fucus evanescens</td>
<td>Macroalgae</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Heterosiphonia japonica</td>
<td>Macroalgae</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Molgula manhattensis</td>
<td>Cnidaria</td>
<td>-</td>
<td>x</td>
</tr>
</tbody>
</table>
Danish hot spots?

- STS locations and bunkering
- Areas of refuge
- Shipyards
- In water hull cleaning
- Marinas
A Danish hot spot for hull NIS?

Kalundborg Fjord - An area of refuge and popular in-water hull cleaning spot

More monitoring, more inspection and better cleaning technology?
Monitoring on vessel

- >2,000 of species are associated with wetted area of Panamax

Monitoring in hot spots?
What can we do -
Action Plan

- Initiate monitoring programme for NIS
- In-water hull cleaning: Assess Best Available Technologies
- Issues for in-water hull cleaning:
  - Niche areas
  - Paint chips and residues
  - Waste and waste water
Danish Nature Agency (2014) “Monitoring of non-indigenous species in Danish marine waters”

- NIVA DK, LITEHAUZ, AkvaplanNIVA
- Monitoring priorities for NIS in combination with existing programme
- Proposed programme
  - 13 hotspots
  - 44 existing stations
  - 48 locations with eDNA
Potential hotspots for “Non-indigenous species in marine waters”

**Figure 1:** Map of the North Sea and the Baltic Sea showing the ports with international ferry services operating between two ports. Colour code indicates the number of ship calls per year. Black: <500, Yellow: 500-1,000, Orange: 1,001-1,500, Red: >1,500. Numbers can be used to identify ports. A complete list is given in Appendix 2.
The MONIS4 NIS monitoring programme

- Coverage of port hot spots
- Data generation
- Comparison of conventional and eDNA species identification

- Sampling:
  - phyto and zooplankton
  - soft substrate
  - hard substrate
  - fish (day and night)
Hard substrate

- Settling plates (PVC) and rope of fixed type and length
  - 9 units in Århus Port and in Esbjerg Port
  - Deployed from early to late summer (May to September)
  - Semi quantitative identification
- Scraping of subsea structures
  - 18 locations in in Århus Port and in Esbjerg Port
  - Qualitative species identification under microscope
**NIS identification with e DNA**

- 20 NIS on Target Species List are analysed with qPCR
  - 32 samples of water column
  - 16 ports

1. Cercopagis pengoi
2. Mnemiopsis leidyi
3. Mya arenaria
4. Crassostrea gigas
5. Acipenser gueldenstaedtii
6. Acipenser ruthenus
7. Paralichthodes camtschaticus
8. Eriocheir sinensis
9. Homarus americanus
10. Oncorhynchus gorbuscha
11. Neogobius melanostomus
12. Oncorhynchus mykiss
13. Colpomenia peregrina
14. Cordylophora caspia
15. Carassius autatus
16. Cyprinus carpio
17. Karenia mikimotoi
18. Pseudochattonella farcimen
19. Pseudochattonella verruculosum
20. Bonnemaisonia hamifera
21. Prorocentrum minimum

- Vandlopp
- Amerikansk ribbegoble
- Sandmusling
- Stillehavsøsters
- Diamant stør
- Sterlet
- Kongekrabbe
- Kinesisk udlåndskrabbe
- Amerikansk hummer
- Pukellaks
- Sortmundet kutling
- Regnbueørred
- Alge, Østerstyv
- Hydroide
- Sølvkarusse
- Karpe
- Dinoflagelat
- Heterokont flagelat
- Heterokont flagelat
- Rødtot alge
- Dinoflagelat
**Summary**

**Do we (Denmark) have a problem?**
- Invasions caused by hull fouling are relatively rare (8/120 years) but on the rise
- After BWMC hulls will be shipping’s largest vector
- EU Marine Strategy Directive requires addressing invasive species (D-2)

**What can we do - inspiration?**
- Voluntary IMO Guideline, regulation in AUS/NZ
- US regulation included in VGP, and US state regulation
- National Danish Guidance?

**Better available technologies?**
- Invasive species hide in places not targeted when cleaning hull for speed
- In-water hull cleaning for NIS not regulated and not incentivised
- Risk Identification tool, onboard monitoring?
Thank you for your attention
www.LITEHAUZ.com
fsl@litehauz.com

Check out our ballast water monitor
bw-monitor.com
In-water cleaning: Risk?

Dr Eugene Georgiades et al.
Biosecurity Risk Analysis (Animals and Aquatic)
Presentation overview

• Context
  – EPA re-assessment of antifouling biocides
  – Australia and New Zealand in-water cleaning guidelines
• Environmental contamination risks of in-water cleaning
• Further thoughts and upcoming research
• Key documents
  – Australian and New Zealand antifouling and in-water cleaning guidelines
  – In-water cleaning of vessels: biosecurity and chemical contamination risks
  – Scenarios of biofouling risk and their management
  – Application of NZ scenarios within the MAMPEC model
    epa.govt.nz/Publications/EPA_AntifoulingPhase2.pdf
NZ EPA re-assessment of antifouling biocides

• To retain an existing approval, the substance must either:
  – pose negligible risks to human health and the environment, or
  – possess benefits which outweigh any un-mitigated risks posed

• Antifouling paints have high generic benefits

• Copper - the principal biocidal component in all NZ-approved antifouling paints

• Some approvals retained even when significant risks exist

New Zealand (and Australia): In-water cleaning

Decision Support Tool

Types of In-water Biofouling Treatment

1. In-water cleaning of submerged surfaces of vessels or movable structures, including niche areas.
   - Adequate documentation available on
     - Presence of anti-fouling coating
     - Anti-fouling coating type
     - Anti-fouling coating age
     - Planned in-service period
   - Adequate documentation not available

2. In-water treatment aimed at killing (but not necessarily removing) biofouling.
   - Treatment acceptable if proposed method:
     - Is endorsed by relevant authority
     - Meets conditions A, B, and C
     - Does not result in release of viable biofouling material exceeding provisions in condition D.

3. In-water cleaning as a result of emergency situation or exceptional circumstances
   - Decision and guidance provided by relevant authority

Discharges meet local standards or requirements - but what are the discharges?

Conditions for removal and/or treatment of biofouling:
- A: Anti-fouling coating is suitable for cleaning/treatment.
- B: Cleaning/treatment method does not damage coating surface.
- C: Discharges meet local standards or requirements.
- D: Cleaning/treatment method ensures that release of biological material into the water column is minimised through the capture and containment of biofouling waste. Cleaning method should aim to; at least, capture debris greater than 50 µm in diameter which will minimise the release of viable adult, juvenile and larval stages of macrofouling.

Regional: In-water cleaning may be acceptable without requirement to contain biofouling waste, provided conditions A, B and C are met.

Domestic: In-water cleaning may be acceptable provided conditions A, B, and C are met. Risk assessment by relevant authority to determine whether condition D must be met.

International: In-water cleaning acceptable only when conditions A, B, C, and D are met, unless specified by relevant authority.

Unknown: Defaults to ‘international’ biofouling origin.
Balancing the risks of in-water cleaning

• Research Question
  - “When do the environmental costs of releasing non-indigenous species and chemical contaminants during in-water cleaning outweigh the risks of no action?”

• Approach taken
  - Key questions
  - Literature review and modelling/risk assessment
  - Combine chemical and biosecurity risk assessments
  - Knowledge gaps?

Morrisey et al. 2013
Vessel dry-docking, Singapore - Daniel Kluza (MPI)
Balancing the risks of in-water cleaning

• Scenarios examined
  – Vessel origin
  – Vessel type
  – Vessel size
  – Paint type
  – Cleaning method
  – Number of vessels cleaned
  – Ports and marinas

Image: Daniel Kluza (MPI)
Chapter 5

Assessment of the chemical contamination risks

• **Question 1:**
  What are the contaminant levels in the water column following in-water cleaning?

• **Question 2:**
  What are the contaminant levels in Question 1 equivalent to in terms of vessel numbers at typical leaching rate?

**Key caveats**

- no effluent treatment
- release from in-water cleaning only

Image: Daniel Kluza (MPI)
Question 1:
What are the contaminant levels in the water column following in-water cleaning?

• Release rates for in-water cleaning
  – Based on
    • Copper content (sound paint; leached layer; biofilm)
    • Layer thickness
    • Removal depth
  – Lower (Soft: 85 µg/cm²; Aggressive: 3145 µg/cm²)
  – Upper (Soft: 625 µg/cm²; Aggressive: 4225 µg/cm²)

• Uncertainties
  – [Copper] in biofilms
  – [Copper] in leached layer
  – Depth of paint removed (cleaning type)
  – Partitioning of copper from removed biofilm and paint into environment
  – Size of mixing zone
Question 1:

What are the contaminant levels in the water column following in-water cleaning?

USEPA acute criteria 4.8 μg/L
<table>
<thead>
<tr>
<th>Surface area (m²)</th>
<th>Length class (m)</th>
<th>0.00274</th>
<th>0.0274</th>
<th>0.137</th>
<th>0.274</th>
<th>1</th>
<th>2</th>
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<tr>
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Low = < 3 µg/L; Medium > 3 µg/L but < 4.8 µg/L; High > 4.8 µg/L
ANZECC 90% chronic guideline
USEPA acute criteria
Risks of in-water cleaning commercial vessels aggressive cleaning (copper release, upper estimate)

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<tr>
<th>Surface area (m²)</th>
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<tr>
<td>Lyttelton (worse case)</td>
<td></td>
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Low = < 3 µg/L; Medium > 3 µg/L but < 4.8 µg/L; High > 4.8 µg/L
Question 2:
What are the contaminant levels in Question 1 equivalent to in terms of vessel numbers at typical \((8.2 \mu g/cm^2/day)\) leaching rate?

<table>
<thead>
<tr>
<th>Equivalent no. of vessels</th>
<th>Soft cleaning</th>
<th>Aggressive cleaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPC-low</td>
<td>17</td>
<td>126</td>
</tr>
<tr>
<td>SPC-high</td>
<td>634</td>
<td>852</td>
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</tbody>
</table>

Typical emissions
- Auckland ~ 10 vessels
- Lyttleton ~ 6 vessels

Comparison of total emission rates for 150-200 m commercial vessels:
In-water cleaning vs. typical leaching rate
## In-water cleaning – risk considerations table

<table>
<thead>
<tr>
<th>Biosecurity</th>
<th>Chemical</th>
<th>Overall decision</th>
<th>Restrictions and alternative actions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Better to clean?</strong></td>
<td><strong>Decision</strong></td>
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<td>International commercial vessels, brush cleaning of soft fouling, biocide-free paint</td>
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</table>

*Upper rate: do not clean ≥ 1 vessel > 100 m or ≥ 0.274 > 200 m in Lyttelton; or > 1 vessel > 200 m in Waitemata (lower release rate)*
## Risks of in-water cleaning commercial vessels
### soft cleaning (copper release, upper estimate)

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Low = < 3 µg/L; Medium > 3 µg/L but < 4.8 µg/L; High > 4.8 µg/L
ANZECC 90% chronic guideline
USEPA acute criteria
### Risks of in-water cleaning commercial vessels

#### Aggressive cleaning (copper release, upper estimate)

<table>
<thead>
<tr>
<th>No. vessels cleaned per day</th>
<th>Lyttelton (worse case)</th>
<th>Waitemata (largest port)</th>
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Low = < 3 µg/L; Medium > 3 µg/L but < 4.8 µg/L; High > 4.8 µg/L
In-water system development

- Biosecurity risk
  - Recapture systems (soft fouling/some hard fouling removal)
  - Demonstrated to filter down to < 12.5 and 5 µm, respectively
- UV-treatment

Chemical contamination risk

- Can meet water quality requirements (soft fouling & slime-layer removal)
- Aggressive cleaning of hard fouling

Further thoughts

Post-system effluent

- Western Australia ~ 250 µg/L*
- San Francisco < 100 µg/L

Total copper PEC in an area (50 x 250 x 12 m) around a commercial vessel during in-water cleaning.
In-water cleaning - system testing

- Test external cleaning systems using MPI framework
- In scope – reactive systems (macro-fouling)
- In scope - metals testing
  - Biofilms
  - Surrounding water
  - Post-system effluent
- In scope – MAMPEC modelling
- Out of scope – proactive cleaning (slime-layer removal)
Want to know more?
3rd ANZPAC Workshop

Save the date: 12-15th September 2017!

For more information: jlewis@eslinkservices.com.au
Acknowledgements

- Service providers
  - NIWA Ltd
  - ES Link Services Pty Ltd

- In kind support
  - Dept. of Fisheries Western Australia
  - Australian Dept. of Agriculture and Water Resources
  - California State Lands Commission
  - Dept. Natural Resources and Land, Hawaii

- MPI
  - MPI Operational Research Team!
  - Biosecurity and Environment Group
  - Response Group
  - Long-term Incursion Management Group

Special thanks!
Lena Granhag
Chalmers University
Gothenburg

Moustaches on lips – Not on ships!!!
Using MAMPEC in Swedish harbours

Erik Ytreberg
Department of Shipping and Marine Technology
Risk assessment

Pressure (Loads of biocides)

MAMPEC model

PEC (Predicted environmental concentrations)

PNEC (Predicted no-effect concentrations)

PEC/PNEC ≤ 1 = Acceptable risk
Test runs in MAMPEC, using a AF paint with a release rate of 10 µg/cm²/d

<table>
<thead>
<tr>
<th></th>
<th>Gothenburg harbour</th>
<th>Oxelösund harbour (Baltic Sea)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEC, Cu (µg/L)</td>
<td>0.07</td>
<td>0.6</td>
</tr>
<tr>
<td>Background, Cu, (µg/L)</td>
<td>0.51</td>
<td>0.69</td>
</tr>
<tr>
<td>PEC + background (µg/L)</td>
<td>0.58</td>
<td>1.29</td>
</tr>
<tr>
<td>PNEC, Cu, (µg/L)</td>
<td>4.3*</td>
<td>1.45*</td>
</tr>
<tr>
<td>PEC/PNEC</td>
<td>0.13</td>
<td>0.89</td>
</tr>
</tbody>
</table>

- Other MAMPEC harbor scenarios can be developed
- With data on hull cleaning emissions one can include that load of biocides to MAMPEC and calculate site-specific PECs
- Even if PEC is low, Best Available Practice needs/should be considered? Question for regulators.

*According to HVMFS 2013:19, and when DOC conc. is unknown
Natural supply of marine organisms vs hull cleaning introductions

Lena Granhag, Dept Shipping and Marine Technology, Chalmers University of Technology
Biofouling and hull cleaning seminar 5th April 2017
Life stages of fouling organisms

Bay barnacle *Amphibalanus improvisus*

Green fouling alga *Ulva* sp.
THE POTENTIAL FOR RELEASE OF VIABLE ORGANISMS DURING CLEANING

- Dependent on type of organism
- Barnacles – baseplate part of animal
- Mussels – byssus treads
THE POTENTIAL FOR RELEASE OF Viable ORGANISMS DURING CLEANING

- Dependent on type of organism
- Some algae -fragments
- Some animals– hydroids fragments
Biofouling succession

Slime-layer also include small stages of macroalgae and invertebrate larvae

- Small barnacles (0.5 mm)
- Large Ulva (cm)
- Small Ulva (10 μm)
- Diatoms (25 μm)
- Barnacles (cm)
Attachment strength of marine organisms versus hull cleaning methods

DINIS OLIVEIRA
PhD student

BIOFOULING AND HULL CLEANING WORKSHOP
Gothenburg, April 5th 2017
BIOFOULING AND HULL ROUGHNESS


Images courtesy of Marinest Shipping AB (Gothenburg, Sweden).
### MOST COMMON SHIP FOULING

<table>
<thead>
<tr>
<th>Micro &lt;1 mm</th>
<th>Macro &gt;1 mm</th>
</tr>
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<tbody>
<tr>
<td><strong>Soft Fouling</strong></td>
<td><strong>Hard Fouling</strong></td>
</tr>
<tr>
<td>“slime”, “grass”</td>
<td>“shells”</td>
</tr>
<tr>
<td><strong>Diatoms:</strong> Amphora, Navicula, …</td>
<td>Larvae and juvenile</td>
</tr>
<tr>
<td><strong>Bacteria:</strong> Cobetia marina, …</td>
<td><strong>Barnacles:</strong> Amphibalanus …</td>
</tr>
<tr>
<td><strong>Algae spore(-lings):</strong> Ulva (Enteromorpha) …</td>
<td><strong>Tubeworms</strong> (Polychaeta)</td>
</tr>
<tr>
<td><strong>Adult algae:</strong> Ulva (Enteromorpha) …</td>
<td><strong>Oysters</strong></td>
</tr>
</tbody>
</table>

Images courtesy of Marininvest Shipping AB (Gothenburg, Sweden).
FOULING CONTROL COATINGS

ANTI-FOULING (AF)
- Biocide release
  - Insoluble matrix
  - Controlled Depletion Polymers
  - Self-Polishing Copolymers

FOUL-RELEASE (FR)
- Non-stick / low adhesion
  - Fluoropolymers
  - Silicones

Images: Dinis Oliveira (2016)
COATING FAILURE

ALGAL GROWTH
- Main biocides not effective (Cu, Zn)
- Booster biocides (herbicides)
- Near waterline ↔ wear belt

HARD FOULING
- Low hydrodynamic stress (aft region)
- Depleted AF, or Low biocide release
- Niche areas

Images: top – Dinis Oliveira (2016); bottom – Marinvest Shipping AB.
UNDERWATER HULL CLEANING


strength = shear stress

waterjet

non-cavitating  cavitating

brushes

0.01 MPa
COMPILATION OF ADHESION STRENGTH

Review

Matching Forces Applied in Underwater Hull Cleaning with Adhesion Strength of Marine Organisms

Dinis Oliveira * and Lena Granhag
ADHESION STRENGTH TESTS

MICRO-FOULING

Turbulent Channel Flow
Schultz (2000)

Waterjet (Finlay et al., 2002)
Spinjet (Cassé et al., 2007)

MACRO-FOULING

ASTM D5618-94 – Force gauge
micro-FOULING ADHESION

Silicone Foul-Release: ~ 0.000010 – 0.000275 MPa

<table>
<thead>
<tr>
<th>Stage</th>
<th>Organism</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adhered cells (2 h)</td>
<td><em>Amphora coffeaeformis</em></td>
<td>Holland et al. (2004)</td>
</tr>
<tr>
<td></td>
<td><em>Navicula incerta</em></td>
<td>Sommer et al. (2010), Mieskin et al. (2012)</td>
</tr>
<tr>
<td></td>
<td><em>Navicula perminuta</em></td>
<td>Holland et al. (2004)</td>
</tr>
<tr>
<td>Biofilm (2 days)</td>
<td><em>Navicula incerta</em></td>
<td>Sommer et al. (2010)</td>
</tr>
<tr>
<td>Sporelings (6 days)</td>
<td><em>Ulva linza</em></td>
<td>Evariste et al. (2012), Ekin et al. (2007), Cassé et al. (2007)</td>
</tr>
<tr>
<td>Sporelings (7 days)</td>
<td><em>Ulva linza</em></td>
<td>Mieskin et al. (2012), Sommer et al. (2010)</td>
</tr>
<tr>
<td>Sporelings (8 days)</td>
<td><em>Ulva linza</em></td>
<td>Chaudhury et al. (2005)</td>
</tr>
<tr>
<td>Sporelings (14 days)</td>
<td><em>Ectocarpus crouaniorum</em></td>
<td>Evariste et al. (2012)</td>
</tr>
<tr>
<td></td>
<td><em>Ectocarpus sp.</em></td>
<td>Evariste et al. (2012)</td>
</tr>
<tr>
<td></td>
<td><em>Hincksia secunda</em></td>
<td>Evariste et al. (2012)</td>
</tr>
</tbody>
</table>

strength = shear stress

waterjet
non-cavitating cavitating

strength = shear stress = 0.01 MPa
MACRO-FOULING ADHESION

Epoxy:
~ 0.3 – 2.2 MPa
Ablative Anti-Fouling:
~ 0.5 MPa

Adhesion strength [MPa]

Organism
Amphibalanus obumae
Amphibalanus obumae
Amphibalanus obumae
Amphibalanus obumae
Balanus amphitrite
Balanus amphitrite
Balanus glandula
Barnacles

Reference
Swain & Schultz (1996)
Swain et al. (1998)
Swain et al. (1998)
Swain et al. (2000)
Swain et al. (2000)
Swain et al. (2000)
Swain et al. (2000)
Tribou & Swain (2015)

strength = shear stress

waterjet
non-cavitating
cavitating

0.01 MPa
MACRO-FOULING ADHESION

Epoxy:
~ 0.3 – 2.2 MPa

Ablative Anti-Fouling:
~ 0.5 MPa

Silicone Foul-Release:
~ 0.03 – 0.5 MPa
CHALLENGES FOR CLEANING

- Cohesive failure (shell breakage)
  - Adhesion strength > Cohesive strength

- Paint strength is variable:
  - Paint type
  - Quality of application
  - Age and history

CHALLENGES FOR CLEANING

- Small radius of curvature
  - variable cleaning strength
  - variable results

Aft region of a product tanker

Image courtesy of Marininvest Shipping AB (Gothenburg, Sweden).
CONCLUSIONS

• Target micro-fouling

• Take into account paint condition:
  • Type and age
  • Quality of application
  • Cause of failure

• Increase paint lifetime
• Minimize emissions to water (paint flakes and dissolved biocides)
KNOWLEDGE GAPS

• Cleaning forces exerted on paint / slime roughness

• Paint wear & damage (conservative threshold)

• Adhesion strength of natural fouling assemblages

• Adhesion strength of fouling on biocide-containing coatings