Biofouling, Biofouling Prevention, and the Environment: The complexities of practical balance

John A Lewis
ES Link Services, Castlemaine, VIC

California NPS Program Interagency Coordinating Committee Antifouling Strategies Workgroup Meeting 18 September 2013
What is “Biofouling”?

“a process of adsorption, colonization, and development of living and non-living material on an immersed substratum”

“The marine world of 10,000 years ago was not characterized by ships, barges, docks, floats, and pilings... Most of the invertebrates 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 the drift logs, most abundant in bays and estuaries...” (MG Hadfield, 1999)
**What are the consequences?**

On vessels:
- Increased hydrodynamic drag
- Reduced speed
- Increased fuel needs
- Accelerated corrosion
- Acoustic noise
- Unsightly

To the environment:
- Increased atmospheric emissions (GHG, PM, SOx, NOx)
- Translocation of invasive species

To the colonies:
- Fouling & degradation of industrial & maritime infrastructure
- Marine community change
Antifouling coatings
  • Biocidal (Toxic)
  • Foul release
Cleaning
  • Careening
  • Slipping/dry-docking
  • In-water
Isolation
  • Dry-berthing

Good biofouling management is not a single strategy, but a combination of strategies
To antifoul or not?
  Yes:
  • Chemical contamination
  No:
  • Efficiency loss (fuel, air emissions)
  • NIS translocation

To clean or not?
  Yes:
  • Chemical contamination
  • NIS release
  No:
  • NIS maturation/release
  • Efficiency loss
  • Someone else’s problem
“Non-indigenous species, along with habitat destruction, the leading cause of extinctions and biodiversity loss worldwide”

“In the marine environment, one of the top five threats to marine ecosystem function and biodiversity”*

Impacts*:
- **Ecological**: Competition, Predation, Altering trophic dynamics, biodiversity or nutrient
- **Economic**: Impacts on maritime industry (fisheries, aquaculture, shipping), Infrastructure damage, Management cost
- **Human health**: Toxic species, Pathogens
- **Socio-cultural**: Amenity, employment, damage to culturally important species or food sources

*Well documented evidence of the impacts of biofouling NIS are few
Not all NIMS are IMS

• Lessepsian migration:
  • “None has proven to damage populations of other species, each having found a narrow previously unoccupied ecological niche, they have thus enhanced local biodiversity” (Meinesz 1999*)

• > 4000 reported fouling species

• Port Phillip Bay, Southern Australia:
  • ~160 NIS (13% of flora/fauna); 8 considered IMS of concern

• of ~1600 global NIS, 53 designated as IMS of concern (Hayes & Sliwa 2005)

...but the baddies are baddies!

*Undaria pinnatifida, Asterias amurensis, Perna viridis, Carcinus maenas, Didemnum vexillum*

...and many others are pesty!

*Hydroides* spp., Amphibalanid & Megabalanid barnacles

...the warning

“Pointing out the many recent introductions tends to minimize the problem posed by the most damaging species. By the precautionary principle, we should attempt generally to limit introductions” (Meinesz, 1999)
The translocation process

<table>
<thead>
<tr>
<th>Translocation process</th>
<th>Selective filters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. COLONISATION</td>
<td>Propagule availability</td>
</tr>
<tr>
<td></td>
<td>Attachment / Entrainment</td>
</tr>
<tr>
<td>2. TRANSLOCATION</td>
<td>Survival</td>
</tr>
<tr>
<td></td>
<td>Environmental conditions</td>
</tr>
<tr>
<td>3. TRANSFER</td>
<td>Environmental conditions</td>
</tr>
<tr>
<td></td>
<td>Propagule release</td>
</tr>
<tr>
<td>4. COLONISATION</td>
<td>Availability of suitable substrate</td>
</tr>
<tr>
<td></td>
<td>Biotic resistance</td>
</tr>
<tr>
<td></td>
<td>Water currents, etc</td>
</tr>
<tr>
<td>5. ESTABLISHMENT</td>
<td>Environmental conditions/compatability</td>
</tr>
<tr>
<td></td>
<td>Availability of suitable substrate</td>
</tr>
<tr>
<td></td>
<td>Community instability</td>
</tr>
<tr>
<td></td>
<td>Further inoculations</td>
</tr>
<tr>
<td></td>
<td>Predation, etc</td>
</tr>
</tbody>
</table>

Donor region

Recipient region
Factors influencing NIS movement

<table>
<thead>
<tr>
<th>Filters</th>
<th>Facilitators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Habitat</td>
<td>Vessel numbers</td>
</tr>
<tr>
<td>Antifouling</td>
<td>Time</td>
</tr>
<tr>
<td>Biogeographic barriers</td>
<td>Connectivity</td>
</tr>
<tr>
<td>Distance</td>
<td>Speed</td>
</tr>
<tr>
<td>Speed</td>
<td>Environmental uniformity</td>
</tr>
<tr>
<td>Filters</td>
<td>Preference/Trait</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>-------------------------------------------------------</td>
</tr>
<tr>
<td>Habitat</td>
<td>Floating substrates</td>
</tr>
<tr>
<td>Antifouling</td>
<td>Biocide tolerance</td>
</tr>
<tr>
<td>Environmental stressors</td>
<td>Broad environmental tolerance</td>
</tr>
<tr>
<td></td>
<td>Resistant life stages</td>
</tr>
<tr>
<td>Distance</td>
<td>Durability</td>
</tr>
<tr>
<td>Speed</td>
<td>Tenacity</td>
</tr>
</tbody>
</table>
### Vessel NIS movement risk

<table>
<thead>
<tr>
<th></th>
<th>Individual</th>
<th></th>
<th>Collective</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Introduction</td>
<td>Spread</td>
<td>Introduction</td>
<td>Spread</td>
</tr>
<tr>
<td><strong>Recreational</strong></td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td><strong>Fishing</strong></td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td><strong>Non-Trading</strong></td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Trading</strong></td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>
Incursion Management

“Prevention is better than cure”

1. COLONISATION
   - Selective filters
     - Propagule availability
     - Attachment / Entrainment

2. TRANSLOCATION
   - Environmental conditions
   - Availability of suitable substrate
   - Environmental conditions
   - Environmental conditions/compatibility

3. TRANSFER
   - Community instability
   - Further inoculations
   - Predation, etc

4. COLONISATION
   - Biotic resistance
   - Water currents, etc

5. ESTABLISHMENT
   - Availability of suitable substrate
   - Community instability
   - Further inoculations
   - Predation, etc

Prevention

Emergency Response

Ongoing Management & Control

Etc…
Undaria pinnatifida
(Japanese kelp)

Dispersion by small vessels in Port Phillip Bay, Australia
What influences NIS colonisation?

Propagule pressure (no of vessels, degree of fouling)
Niche availability (new structures, disturbance)

Habitat
- Piers, pontoons, rock walls, boats
- Shading

Lack of competition
Low water exchange

Friends & family

Species in boat harbours will have:
- r-selection life histories
- Broad environmental tolerance
  - Temperature
  - Turbidity
  - Shade
  - Copper
Boat harbours:

- Are not natural environments
• Do not foster native communities
Antifouling paint development

- Pre-18th C: Beaching, careening, pitch & tar
- 1758: Copper sheathing
- 1860s: Copper “paints”
- 1950s: Copper, mercury, arsenic paints
  Soluble matrix, Contact leaching
- 1960s: Organotin biocides
- 1970s: Self-polishing copolymer paints
- 1990-2000s: TBT banned
- 21st C: Copper SPCs, safer co-biocides

* Except for aluminium hulls

* Copper has been a mainstay of antifouling for 250 years
Biocide release rates

Exponential decline in free-association paints (soluble matrix & diffusion systems)

Constant in copolymer systems

Minimum effective release rate
Antifouling biocides need to be:

Toxic, yet non-toxic
Stable, yet unstable
Broad spectrum, yet not too broad
Leachable, but not too fast, nor too slow

Co-biocides: Diuron, Irgarol, DCOI, ZPT, CPT, Dichlofluanid, Tralopyril
### Antifouling Options - Paint Type

<table>
<thead>
<tr>
<th>Paint Type</th>
<th>Effective life (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper-based conventional</td>
<td>12 – 24</td>
</tr>
<tr>
<td>Copper-based erodible</td>
<td>36</td>
</tr>
<tr>
<td>Copper-based SPC</td>
<td>60</td>
</tr>
<tr>
<td>Biocide-free fouling release</td>
<td>&gt; 60 but....</td>
</tr>
<tr>
<td>Novel technologies</td>
<td>unproven</td>
</tr>
<tr>
<td>&quot;natural products&quot;, fibre coatings etc.</td>
<td></td>
</tr>
</tbody>
</table>
What is an effective antifouling?

Biocidal:
- Continuous copper release rate from stationary hull:
  - $> 10 \, \mu \text{g} \, \text{Cu/cm}^2/\text{day}$
  - Short half life co-biocide (algaecide/slimicide)

Non-biocidal:
- Self-cleans @ $\geq 15$ knots on high activity vessels

*Hull niches cannot always be effectively antifouled
• The advent of TBT increased NIS translocation by increasing docking intervals
• The demise of TBT has increased IMS threat facilitating harbour colonisation
In-water Cleaning

- Established growth creates:
  - a performance/fuel penalty
  - an NIS movement risk

“Clean before you leave”

- In-water cleaning can:
  - Release NIS propagules
  - Stimulate spawning
  - Cross-contaminate vessels
  - Release biocide pulses
Controlled in-water cleaning:

“On 26 June 2013, the Standing Council on Primary Industries endorsed the “Anti-fouling and in-water cleaning guidelines”


“These guidelines replace the ANZECC Code of Practice for Antifouling and In-water cleaning and Maintenance, 1997”
General recommendations for in-water cleaning in [Australian] waters:

• A slime layer on a vessel, regardless of origin, may be removed without full containment of biofouling waste, providing a gentle, non-abrasive technique is used.

• Macrofouling acquired outside Australia should not be cleaned in-water if technology is not available to minimise release of viable biological material into the water column*.

• Macrofouling acquired in another region within Australia should not be cleaned in-water unless a risk assessment determines that the biofouling is of low biosecurity risk. The coating should also be suitable for cleaning and the method used should not damage the coating surface or release amounts of contaminant into the environment that exceeds local standards or requirement.

• Locally acquired macrofouling may be cleaned in-water providing the coating is suitable for cleaning and the cleaning method does not damage the coating surface or release unsuitable amounts of contaminant into the environment. The biofouling waste does not need to be contained.

* > 50 microns
“When do the environmental costs of releasing non-indigenous species and chemical contaminants during in-water cleaning outweigh the risks of no action?”

In-water cleaning of vessels: Biosecurity and chemical contamination risks
D Morrisey, J Gadd, M Page, O Floerl, C Woods, J Lewis, A Bell & E Georgiades

MPI Technical Paper No: 2013/11
New Zealand Government Ministry for Primary Industries

The requirement:
  Clear, practical & realistic objectives

The decision process:
  What is acceptable? Relativity of risks & hazards. Where lies the balance?

The outcome:
  Against an acceptance of some impact, the minimisation of additional, unnecessary impact

The approach:
  Proactive & continuous biofouling management
How are biofouling risks best managed?

Proactive antifouling prevention:

• External- Effective antifouling coatings

• Internal- Marine Growth Prevention Systems / antifouling material (e.g. CuNi)

• Prescribed dry-docking intervals

Additional hull husbandry

• Controlled in-water cleaning

• Internal- Chemical (acid, disinfectant), physico-chemical (temperature, salinity, deoxygenation)