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

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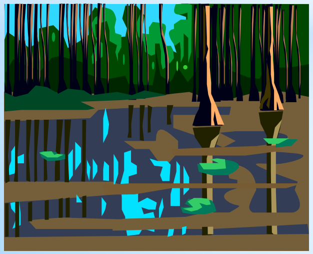
*What is "Biofouling"?

"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

*How do we manage biofouling?

Antifouling coatings

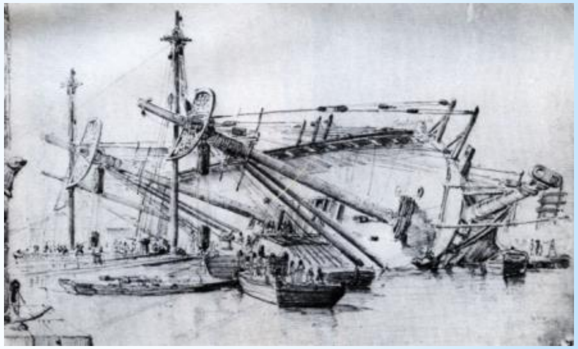
- Biocidal (Toxic)
- Foul release

Cleaning

- Careening
- Slipping/dry-docking
- In-water

Isolation

- Dry-berthing



Good biofouling management is not a single strategy, but a combination of strategies

*What is the dilemma?

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 (NIS) & Invasive marine species (IMS)

"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**

*NIS & IMS

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)

*A Meinesz (1999) *Killer Algae: The true tale of a biological invasion.* University of Chicago Press

*NIS & IMS

...but the baddies are baddies!

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

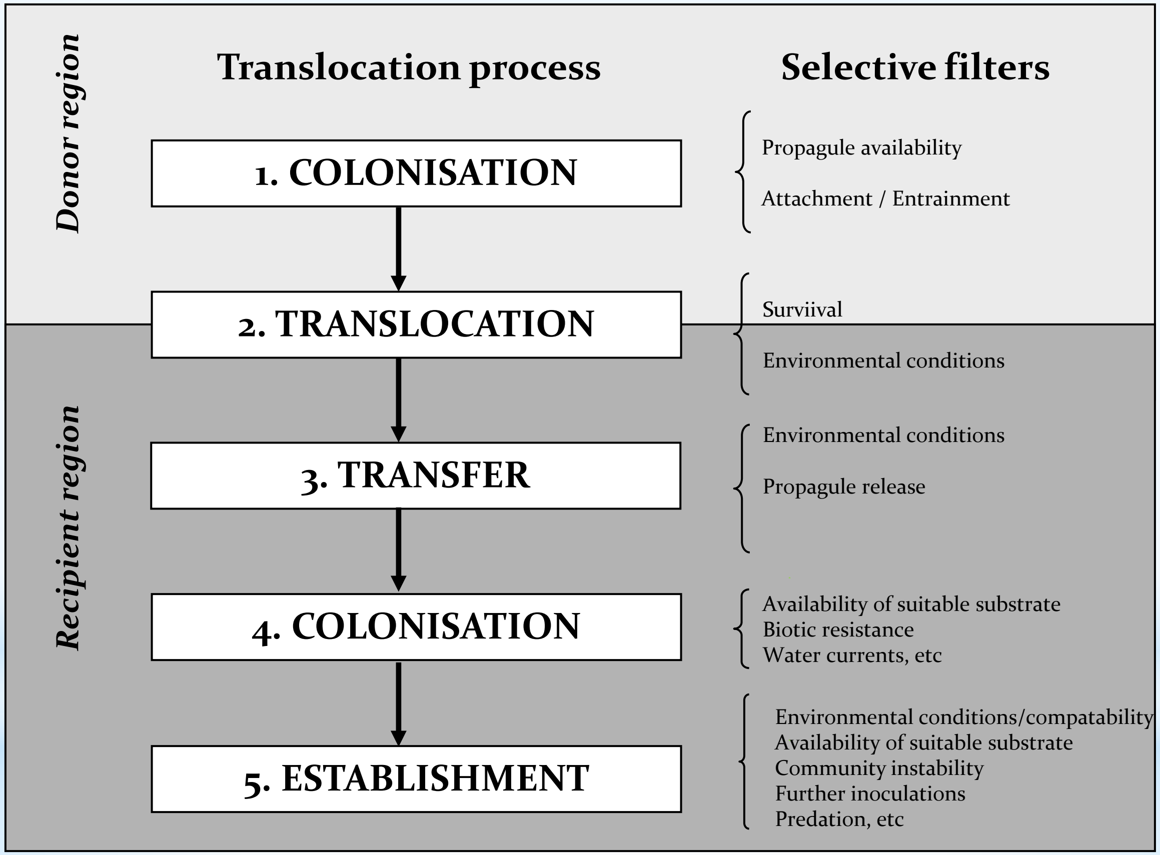
...and many others are pesty!

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



*Factors influencing NIS movement

Filters	Facilitators
Habitat	Vessel numbers
Antifouling	Time
Biogeographic barriers	Connectivity
Distance	Speed
Speed	Environmental uniformity

*NIS traits facilitating movement

Filters	Preference/Trait
Habitat	Floating substrates
Antifouling	Biocide tolerance
Environmental stressors	Broad environmental tolerance Resistant life stages
Distance	Durability
Speed	Tenacity

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*Vessel NIS movement risk

	Individual		Collective	
	Introduction	Spread	Introduction	Spread
Recreational	High	Low	High	High
Fishing	Medium	Medium	Medium	High
Non-Trading	High	High	Medium	Low
Trading	Low	Low	High	Low

*Incursion Management

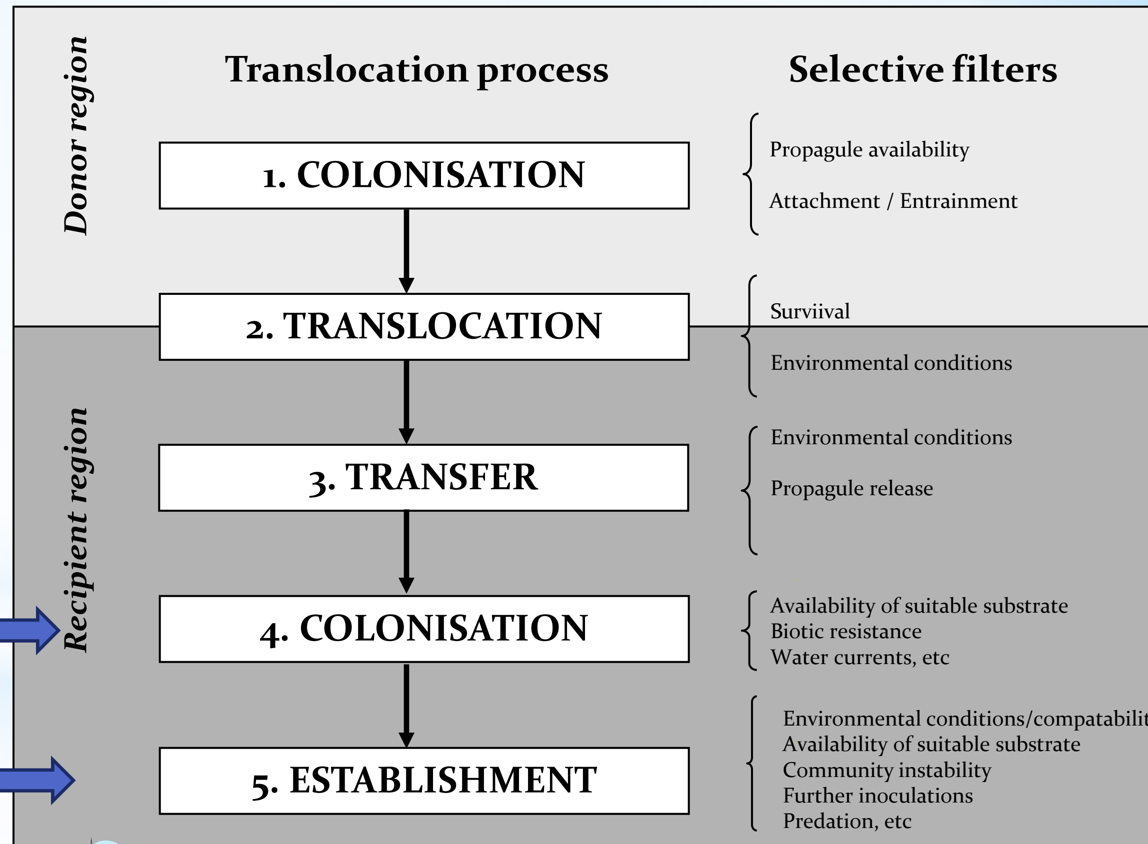
"Prevention is better than cure"

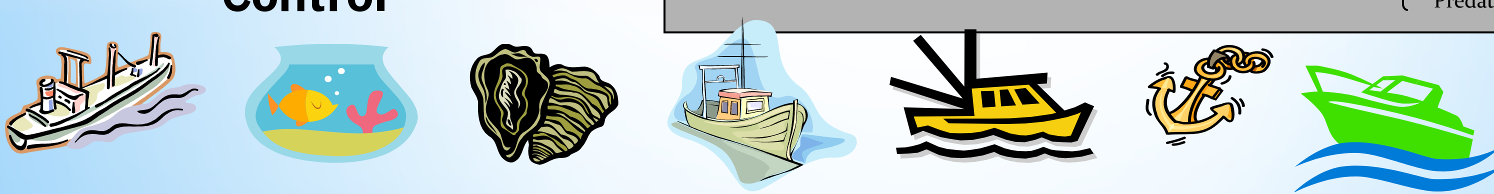
Prevention

Emergency Response

$$$

Ongoing Management & Control





Etc...

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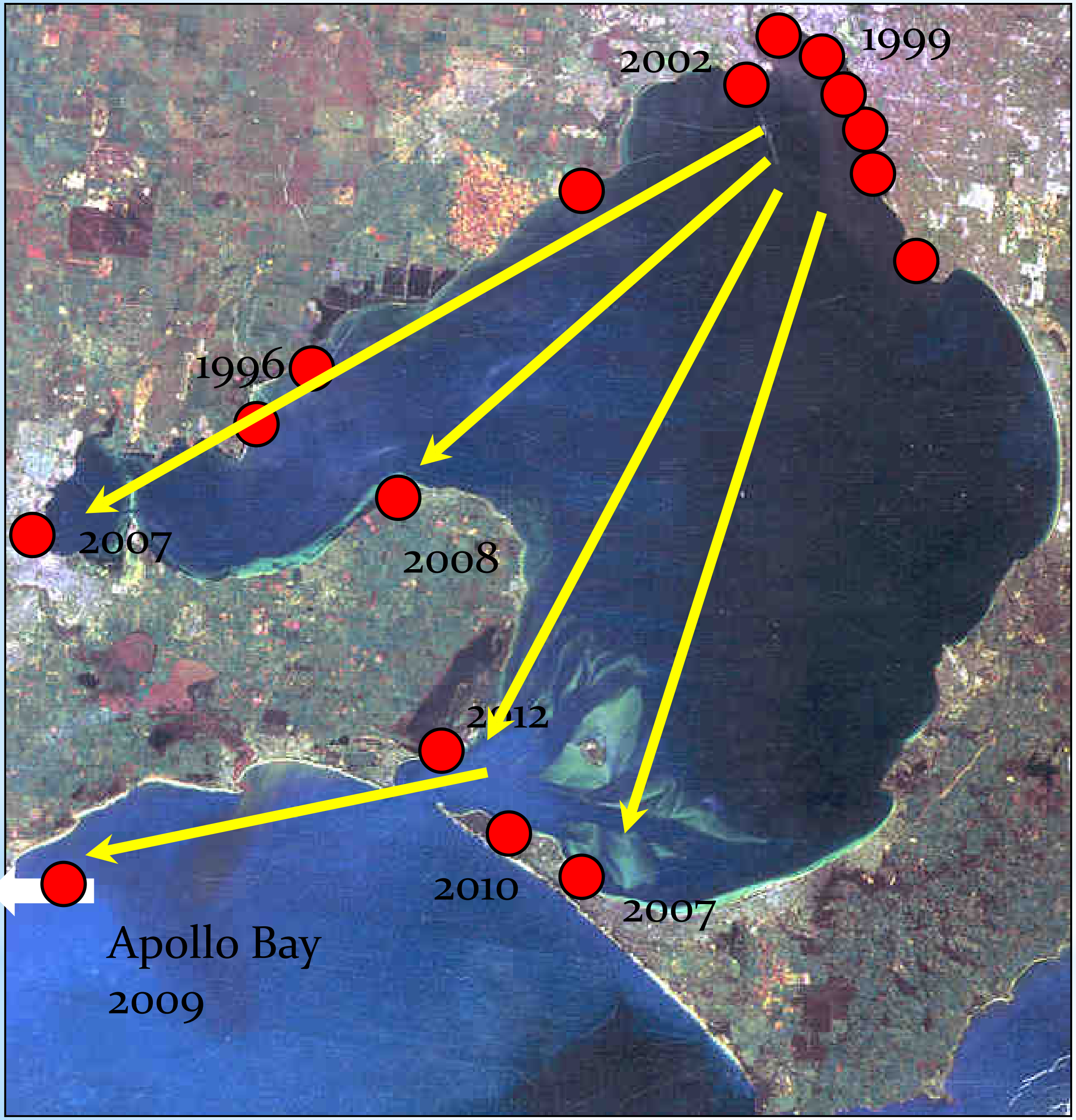


Undaria pinnatifida
(Japanese kelp)

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, disturbance0
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

*Boat harbours:

- Do not foster native communities

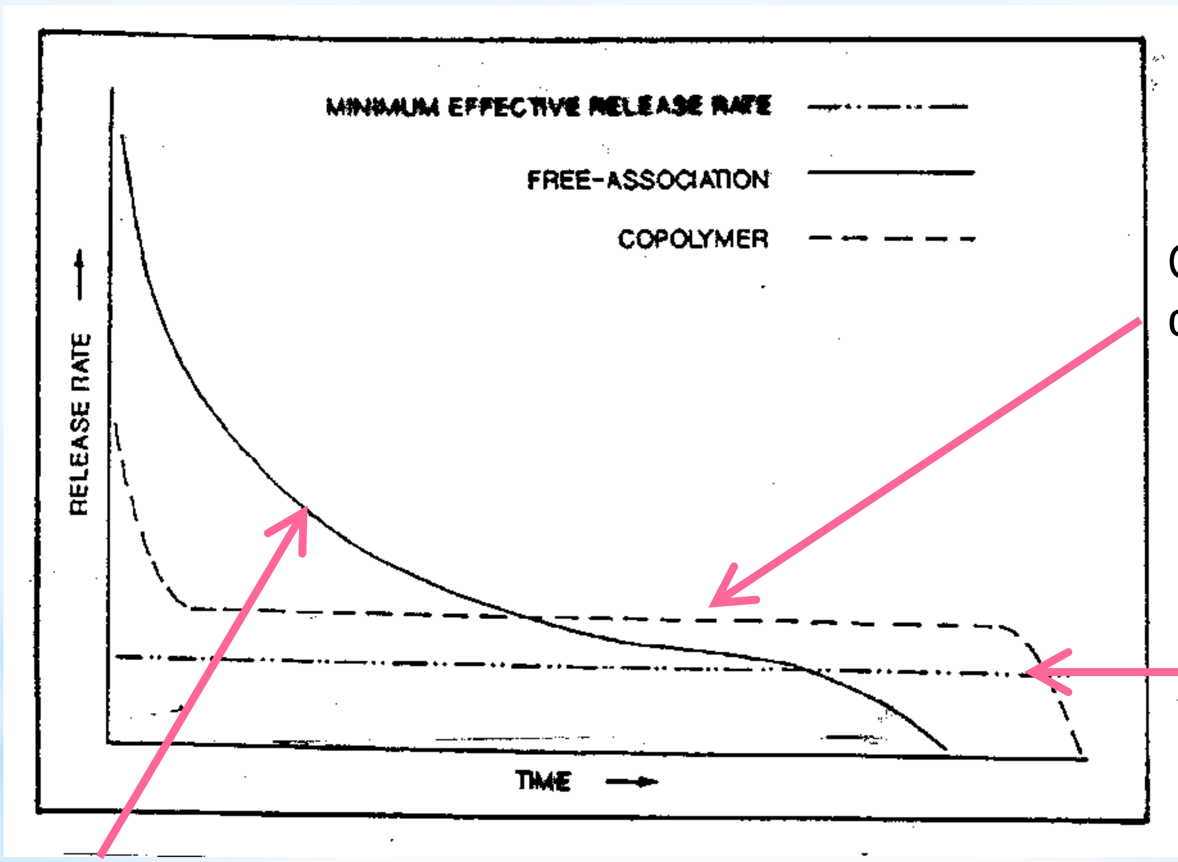
*Antifouling paint development

		Effective life
• Pre-18th C	Beaching, careening, pitch & tar	
• 1758	Copper sheathing	
• 1860s	Copper “paints”	
• 1950s	Copper, mercury, arsenic paints Soluble matrix, Contact leaching	18 – 24 mth (1950s–1960s)
• 1960s	Organotin biocides	
• 1970s	Self-polishing copolymer paints	36 – 60 mth* (1970s–21st C)
• 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



Constant in copolymer systems

Minimum effective release rate

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

*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

Paint Type	Effective life (months)
Copper-based conventional	12 – 24
Copper-based erodible	36
Copper-based SPC	60
Biocide-free fouling release	> 60 but….
Novel technologies "natural products", fibre coatings etc.	unproven

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*What is an effective antifouling?

Biocidal:

- Continuous copper release rate from stationary hull:
  - $\geq$ 10 µg Cu/cm^2/day
- Short half life co-biocide (algaecide/slimicide)

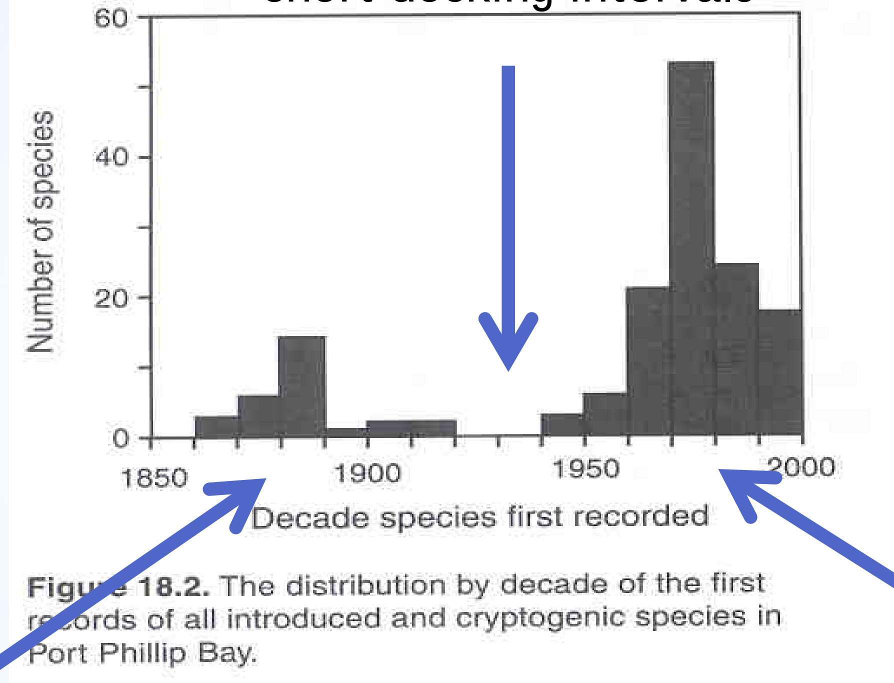
Non-biocidal:

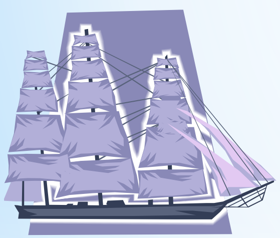
- Self-cleans @ $\geq$ 15 knots on high activity vessels

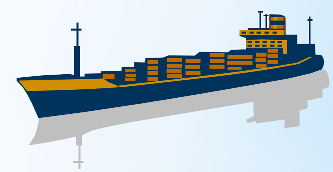
*Hull niches cannot always be effectively antifouled

Nasty stuff

Short docking intervals







Cu Antifouling

TBT Antifouling

- 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

*In-water Cleaning Guidelines

Controlled in-water cleaning:

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

http://www.daff.gov.au/__data/assets/pdf_file/0020/2330570/antifouling-guidelines-june-2013.pdf

“These guidelines replace the *ANZECC Code of Practice for Antifouling and In-water cleaning and Maintenance, 1997*”

*In-water Cleaning Guidelines

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.

*$\geq$ 50 microns

*In-water Cleaning

"*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

http://www.mpi.govt.nz/Default.aspx?TabId=126&id=1836

*Is there a balance?

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)