NIWA
Taihoro Nukurangi

Temporal Development of Biofouling Assemblages

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Cover image: The Mediterranean fanworm, *Sabella spallanzanii*, in a biofouling assemblage [Serena Wilkens, NIWA]

Contents

Tables

Figures

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Executive summary

A literature review was conducted to evaluate the development of biofouling assemblages on non-toxic substrates following immersion periods of 1 – 4 weeks, in both temperate and tropical climates. The Australian Department of Agriculture, Fisheries and Forestry (DAFF) requires this information to determine whether vessels undergoing hull cleaning in foreign ports may become recolonised by local biota following cleaning if they reside in these ports for a further 1 – 4 weeks following cleaning prior to departing for Australia.

Our review suggested that biofouling organisms are able to recruit to susceptible surfaces within 1 week of immersion. These surfaces include hull areas not coated in antifouling paint as well as areas coated in ineffectual antifouling paint. However, reports are inconsistent and biofouling does not always accumulate within 1 week. Especially in temperate latitudes, the intensity of recruitment by biofouling organisms tends to be seasonal and may be limited during colder periods of the year. In contrast, recruitment of biofouling organisms in the tropics is not as seasonal and occurs throughout the year.

Depending on geographical location and season, moderate to extensive biofouling assemblages featuring dozens to hundreds of individuals and colonies per 10 x 10 cm may develop on cleaned hulls over a 3 – 4 week timeframe.

A proportion of these organisms will most likely perish from either natural (stochastic mortality, predation, rainfall) or anthropogenic influences (pollution) before a vessel leaves for Australia. Further mortality is likely to occur *en route*, depending on travel speed and duration.

Trained field officers will be unable to identify in the field the majority of species currently considered to pose a medium, high or extreme biosecurity risk to Australia if specimens have an age of 1 – 4 weeks. Some species may be identified to family level. Taxonomic specialists will be able to identify most 3-4 week old specimens collected in temperate environments to family or genus level. Because of the faster growth rates of many sessile species in tropical latitudes, identification to family or genus level may be achieved 1 week sooner if recruitment occurred in the tropics.

1 Introduction

In April 2010, the Australian Department of Agriculture, Fisheries and Forestry (DAFF) contracted NIWA to conduct a literature review of the rates of biofouling accumulation on submerged surfaces in temperate and tropical locations. DAFF requires this information to support the development of policy for managing biofouling threats to Australia. Of particular interest to the Department is information on the relationship between the time a vessel spends in a foreign port following hull cleaning (in-water or shore-based) and the likelihood that its hull will become recolonised by biofouling organisms prior to departing for, or during calls to other ports *en-route* to Australia. Depending on the age of these biofouling assemblages, it may not be easy or possible to identify them to species level during routine hull surveys.

The aim of this project was to collect and summarise information on the development of biofouling assemblages on susceptible vessel hulls over a 1-month period, and on the likelihood that collected specimens could be identified to species level.

The specific objectives of this literature review were to summarise information on:

1. The rate of accumulation of biofouling organisms on submerged surfaces in weekly increments over 4 weeks for both tropical and temperate climates (worldwide);
2. The survival of biofouling organisms from the point of settlement over time (4 weeks); and
3. The ability to identify biofouling organisms from tropical and temperate climates at a range of age classes (1–4 weeks).

2 Methods

2.1 Biofouling accumulation on submerged surfaces over time

Biofouling assemblages develop on surfaces submerged throughout the world's oceans, but the composition and intensity of biofouling varies widely in space (e.g. between climate regions, different physical environments, depth, etc.) and time (season, immersion period, etc.) (Dürr 2010 and references therein). We undertook a literature review to collate information on the types of biofouling organisms that are likely to colonise non-toxic surfaces within 1 month of immersion in temperate and tropical coastal waters, where possible at weekly intervals.

We gave particular attention to studies conducted within, or in the vicinity of, port and harbour environments. For simplicity, broad climate zones of Temperate (between 23.5 and 66.5 degrees of latitude) and Tropical (0 – 23.5 degrees) were used. Within these two broad categories are included subtropical (20 – 40 degrees) and subarctic/subantarctic climate zones (50 – 70 degrees).

Using the limited information available, we also discuss how colonisation patterns may differ between entirely non-toxic surfaces and surfaces coated in antifouling paint that has no or limited biocide remaining ("ineffectual" coatings), particularly following in-water cleaning of vessel hulls.

The review was conducted by accessing peer-reviewed scientific publications (journal articles, books and book chapters), technical reports and unpublished datasets. We identified these resources by querying literature databases (e.g. ISI Web of Science; Google Scholar), direct contact with relevant specialists and from our own collection of relevant publications in this field. As outlined in the project proposal and contract, the project's budget and timeline limited the amount of relevant information that could be reviewed on biofouling accumulation. However, we took care to ensure that our review targeted the most relevant sources of information.

2.2 Survival of biofouling organisms

Biofouling organisms that have colonised the hull of vessels intending to travel from an international location to Australia may not arrive in a viable state. Sources of mortality include natural mortality (e.g. predation, competition) and mortality caused by the voyage to Australia (e.g. damage incurred from hydrodynamic drag; starvation, etc.). We conducted a literature review to determine the likely rates of survival of different biofouling taxa travelling to an Australian port from overseas. The methods used to identify relevant sources of information are the same as those described in Section 3.1.

2.3 Ability to identify biofouling organisms during the first 4 weeks following settlement

The ease with which biofouling organisms can be identified to species level is often highly dependent on their stage of development. Morphological characteristics that distinguish one species from another are often not present in juvenile organisms. The reliable identification of even high-profile marine pest species can be challenging if available specimens are only days or weeks old. Our aim was to determine whether, and how easily, biofouling

organisms of an age of 1–4 weeks (following settlement) can be identified to species level. This information will enable DAFF to consider the feasibility and design of field-based quarantine checks for biofouling target species.

The following information was collated for this report:

> The likely size and appearance of 1–4 week old recruits of major biofouling taxa in temperate and tropical environments; and
>
> The ability of (i) a field officer with a general understanding of marine biofouling taxa and some training in the identification of target species, and (ii) a recognised taxonomic expert, to identify a range of marine biofouling taxa (and species) at ages of 1–4 weeks following settlement.

In consultation with the DAFF Project Manager, we decided that our assessment of the ease of identification of biofouling species at an early stage would focus on a subset of the list of marine non-indigenous species that were identified in a recent DAFF risk analysis as posing a moderate, high or extreme overall risk to Australia. Because this list did not contain species belonging to all major biofouling taxa (e.g. it lacks bryozoa, hydroids, solitary ascidians and sabellid polychaetes) we supplemented it with example species belonging to these missing groups. Some of these species are already established in Australia but are used in this report to illustrate the ability to identify them or similar species at different early ages. A complete list of these species is presented in the Results section of this report.

Information on the appearance and ease of identification of biofouling taxa and target species was obtained from two sources: (1) from managers of NIWA's Marine Invasive Taxonomic Service (MITS) who process and identify a wide range of marine species on a daily basis and manage and maintain NIWA's extensive biological specimen collections, and (2) from NIWA's in-house taxonomic experts who are recognised experts in their field and who provide specialist identification services for a range of biosecurity and biodiversity projects on an on-going basis.

3 Review: Biofouling accumulation on submerged surfaces over time

3.1 Interpretation of literature summaries presented

The level of detail in which colonisation patterns are reported in the literature varies between studies. For example, studies focused on particular species or taxa may not record the presence of other types of recruits on experimental surfaces (e.g. Hurlbut, 1991). Likewise, studies specifically targeted at sessile species do not often record the presence of mobile organisms associated with biofouling assemblages, and also do not employ methods designed to prevent the loss of mobile organisms during retrieval of settlement substrates (e.g. enclosing the surfaces before they are retrieved). For these reasons the taxonomic lists provided in some studies are likely to be incomplete. In addition, factors such as substrate material, substrate orientation and deployment depth, and sampling effort (number of experimental surfaces) vary widely between studies, yet can significantly affect biofouling recruitment, diversity/richness and community composition (Richmond and Seed 1991; Glasby 2001). These issues complicate attempts to generalise biofouling recruitment patterns, and they may not accurately reflect biofouling recruitment to vessels.

We have attempted to present our summaries of biofouling patterns in a clear and intuitive manner that considers potential confounding factors. We have also excluded microbial films ('biofilms') in our description of biofouling accumulation. Biofilms develop on *any* surface submerged in the sea and are a prerequisite of macro-fouling assemblages (Dobretsov et al. 2010). They can thus be assumed to have been present on any of the substrates examined by the studies we reviewed - yet they are infrequently included in taxonomic summaries, which are mostly restricted to macro- biota. Recruitment is often defined heuristically, i.e. according to the purposes of specific studies or experiments. For the purposes of this review, we defined "recruitment" as the detection of an organism on a surface by an observer. For most studies, this involved the presence of individuals or colonies that could be observed with the naked eye. A large number of well-designed studies have investigated biofouling accumulation to non-toxic substrates over longer time frames (months to years) (e.g. Greene et al. 1983; Glasby 2001; Lin and Shao 2002; Dafforn et al. 2008; Pierri et al. 2010). Such studies were excluded from our review as they did not possess relevant short-term (≤ 4 weeks) data.

3.2 Biofouling accumulation in temperate environments

We reviewed 19 studies that examined the accumulation of biofouling on non-toxic surfaces for periods of up to 4 weeks from immersion of the surfaces. The presence of biofouling taxa over time, and the frequency at which biofouling was recorded at different time periods (1, 2, 3 or 4 weeks) in the 19 studies are summarized in Figure 3-1. Details on the design of the individual studies (e.g. substrate type used, author details) are presented in Appendix 1.

Over a period of 4 weeks, diverse assemblages of biofouling organisms can develop on non-toxic surfaces in temperate marine environments. A total of 18 taxonomic groupings belonging to nine marine phyla were recorded from experimental surfaces used in the 19 studies. Seven taxonomic groups (hydroids, encrusting bryozoans, barnacles, calcareous tubeworms, gastropods, sponges and solitary ascidians), were encountered in at least one

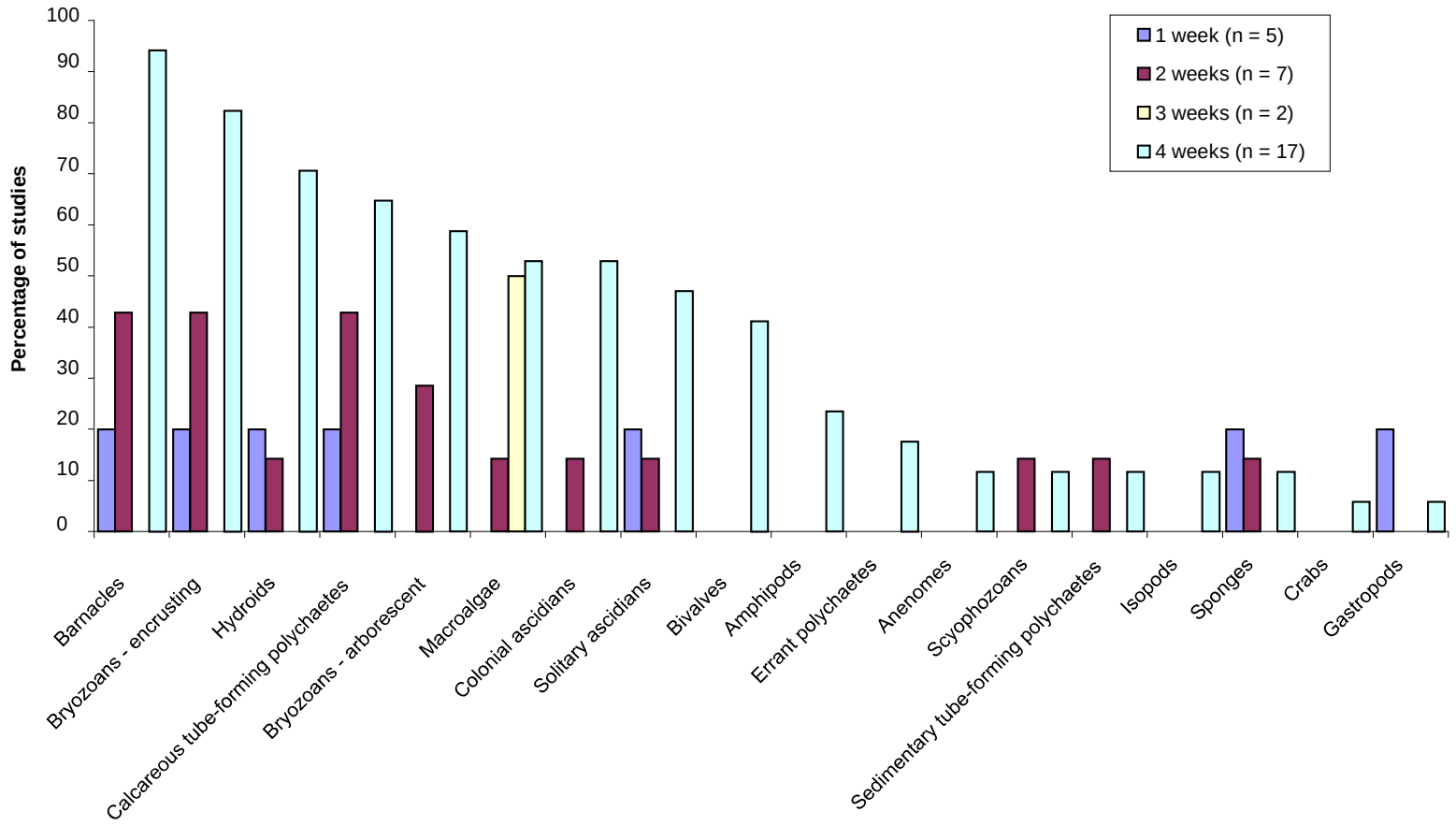

Figure 3-1: Summary of short-term (< 4 weeks) biofouling accumulation to non-toxic surfaces in temperate marine environments on a weekly basis. Bars represent the percentage of the total number of studies examined in which recruitment of different biofouling taxa had been noted after 1, 2, 3 and 4 weeks. Study-specific details on biofouling accumulation are provided in Appendix 1.

study after an immersion period of only 1 week. However, each of these taxa was recorded in only one out of the five studies that measured recruitment after 1 week. Additional taxa were reported following 2 weeks of immersion (macroalgae, scyphozoans, arborescent bryozoans, polychaetes inhabiting soft tubes and colonial ascidians). There was also little consistency among the studies in the composition of the assemblages after 2 weeks (Figure 3-1). However, some taxa, notably bryozoans, barnacles and calcareous tubeworms, occurred reasonably consistently and were recorded in up to 43 % of studies. Few data were available to evaluate biofouling accumulation during a 3-week immersion period as only two studies examined this timeframe, of which one recorded exclusively macroalgae. All 18 of the taxonomic groups presented in Figure 3-1 were reported from surfaces immersed for a period of 4 weeks. The biofoulers that were most consistently recorded after 4 weeks were barnacles (94 % of studies), bryozoans (82 %), calcareous tubeworms (65 %), hydroids (71 %), ascidians (53 %), macroalgae (71 %) and bivalves (41 %). Sponges, anemones and mobile organisms were encountered less frequently (Figure 3-1). We have not presented the taxonomic records over time as cumulative presence in which case a taxon could be considered as being able to occur at any time from the shortest immersion period it was first reported. However, we suggest that this interpretation may not be unreasonable, as we suspect that the sparse presence of taxa on surfaces immersed for a 3-week period (Figure 3-1) is an artefact of the restricted number of studies we reviewed and the focus of these studies.

The density at which biofouling organisms recruited to substrates immersed for 1 – 4 weeks varied considerably between studies and was not consistently available for most taxa. However, it is evident that even after short periods of immersion (1 – 2 weeks) notorious biofouling groups can attain large abundance on submerged substrates. For example, after 2 weeks, up to 27 encrusting bryozoans, 5 arborescent bryozoans, 1,600 barnacles and 220 tubeworms could recruit per 10 x 10 cm area of substratum (Table 3-1). After an immersion period of 4 weeks, densities of biofouling groups reported in the literature were generally considerably higher than after 2 weeks immersion.

3.3 Biofouling accumulation in tropical environments

Twelve studies were reviewed that examined the development of biofouling assemblages over a 4-week period in tropical environments. Biofouling organisms belonging to 18 taxonomic groups were reported. One out of three studies recorded biofouling organisms on experimental surfaces after 1-week's immersion. These comprised hydroids and nematode worms (Figure 3-2). After 2 weeks' immersion, a total of 16 taxa were recorded, some of which occurred consistently across most studies: barnacles (100 % of studies), amphipods and bivalves (67 %), hydroids, tubeworms, ascidians (60 %) and bryozoans (33 %) (Figure 3-2). As in temperate environments, most taxonomic groups were encountered following 4 weeks of immersion. Hydroids, bryozoans, barnacles, calcareous tubeworms, amphipods, bivalves and colonial and solitary ascidians were recorded in 45 – 89 % of the studies reviewed.

The density at which biofouling organisms can recruit to submerged substrates in the tropics over a short timeframe is considerable. Following a 2-week immersion period, dozens of bryozoans, ascidians, and nematodes, hundreds of hydroids, polychaetes and bivalves, and thousands of barnacles and tube-dwelling amphipods, were reported from artificial substrates used in the studies we reviewed (Table 3-2). For some taxa, such as hydroids,

bryozoans, nematodes, calcareous tubeworms and solitary ascidians, these densities increased with an increase in immersion period.

Table 3-1: Short-term (<4 weeks) examples of settlement and recruitment density (number of colonies or individuals per cm^2) of various biofouling taxa to non-taxa surfaces in temperate marine environments on a per-week basis. Where multiple estimates were available in the literature, they are presented as ranges. Literature sources are provided in table footnote.

Taxon	Week 1	Week 2	Week 3	Week 4
Macroalgae				9
Hydroids				1 – 273
Anenomes				9
Scyophozoans		150		
Bryozones – encrusting	26	270		1 – 88
Bryozones – arborescent		5		1-75
Barnacles		1600		5 – 1870
Calcareous tube-forming polychaetes	12	5 – 220		2- 5280
Seimentary tube-forming polychaetes				18
Errant polychaetes				23
Isopods				37
Amphipods				1100
Bivalves				0.03 – 5910
Gastropods				1
Sponges				62
Colonial ascidians	4			1-17

Literature soures: Scheer (1945); Skerman (1958); Skerman (1959); Chalmer (1982; El-Komi (1991); Henrikson and Pawlik (1995); Fairfull and Harriott (1999); Johnston and Keough (2000); Berntsson and Jonsson (2003); Bullard et a. (2004); Darbyson et al. (2009)

Table 3-2: Short-term (<4 weeks) examples of settlement and recruitment density (number of colonies or individuals per cm^2) of various biofouling taxa to non-taxa surfaces in tropical marine environments on a per-week basis. Where multiple estimates were available in the literature, they are presented as ranges. Literature sources are provided in table footnote.

Taxon	Week 1	Week 2	Week 3	Week 4
Hydroids		14 – 70	80	140
Bryozones – encrusting		0..1	1	2
Bryozones – arborescent		3	9	7 - 800
Nematodes	2	40	50	140
Calcareous tube-forming polychaetes		17 -19	17	29 -300
Seimentary tube-forming polychaetes		440		
Errant polychaetes		28		
Amphipods		1 -1250	5 – 23	1 – 300
Bivalves		0.2 – 1.5	0.3	0.3 – 4
Sponges				0.1
Colonial ascidians		0.3 =- 30	1	1
Solitary ascidians		0.1	14	17

Literature sources: Lee and Trott (1973); Floerl (2002); Johnston et al. (2002); da Fonsêca-Genevois et al. (2006); Satheesh and Wesley(2008a, b)

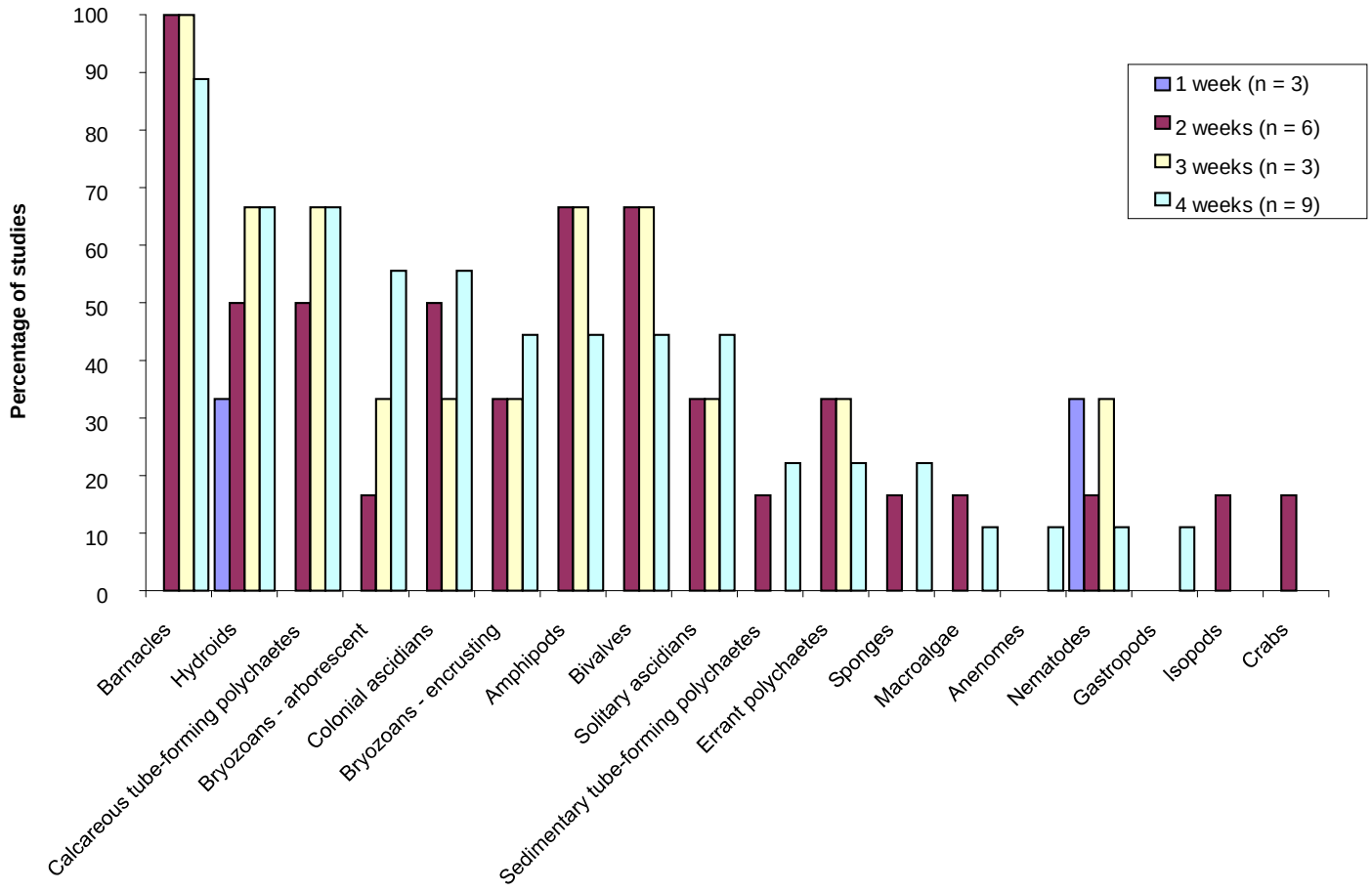

Figure 3-2: Summary of short-term (≤ 4 weeks) biofouling accumulation to non-toxic surfaces in tropical **marine environments on a weekly basis.** Bars represent the percentage of the total number of studies examined in which recruitment of different biofouling taxa had been noted after 1, 2, 3 and 4 weeks. Study-specific details on biofouling accumulation are provided in Appendix 1.

4 Review: Survival of biofouling organisms

Not all of the biofouling organisms that settle on a submerged surface will survive to become reproductively active adults. A range of natural and anthropogenic factors cause mortality of juvenile and adult marine benthic biota. In the context of vessel biofouling, sources of mortality can be separated into two categories. The first category includes those acting upon biofouling assemblages when they are stationary (e.g. when a vessel is moored in a port or at anchor in shallow waters). Here, mortality can be caused by natural factors, such as senescence, predation, competition, disease, variation in water temperature, salinity or oxygen levels, or by anthropogenic influences (e.g. environmental pollutants) (Day and Osman 1981; Hurlbut 1991; Osman and Whitlatch 1995; Gosselin and Qian 1997; Hunt and Scheibling 1997; Holloway and Connell 2002; Johnston et al. 2003; Boyle et al. 2007). The second category of mortality acts upon biofouling organisms when a vessel is moving between destinations. Here, damage or mortality can be caused by hydrodynamic forces (drag), starvation (e.g. inability to filter-feed) or exposure to unsuitable environmental conditions (e.g. transport of cold-water species to tropical latitudes, or passage through low-salinity or freshwater environments) (Minchin and Gollasch 2003; Coutts et al. 2009).

4.1 Mortality during stationary periods

Gosselin and Qian (1997) and Hunt and Scheibling (1997) reviewed natural mortality and survival of marine invertebrate species that included bivalves, gastropods, barnacles, ascidians, and bryozoans. Both studies found mortality is highest in the first few months following settlement such that, by the age of 4 months, cohorts are generally reduced to < 20% of their initial numbers. The results of both studies (and others) pertaining to mortality during the first month following settlement are presented in Table 4-1. Natural mortality rates of marine invertebrates are highly variable (as evidenced by the wide ranges) and suggest that a significant proportion of recruits are removed from a cohort on a weekly basis. For example, up to 78 % of juvenile barnacles and 43 to 90 % of solitary and colonial ascidians, respectively, may perish during the first week following settlement. Of the species examined by these two studies, bryozoans and bivalves generally displayed the smallest rates of mortality. It is not known whether these rates of natural mortality (mostly observed in benthic environments) directly apply to biofouling assemblages on vessel hulls, which might be less accessible to mobile benthic predators than regular benthic substrates.

Survival of biofouling assemblages in port and harbour environments can also be affected by sudden disturbances such as chemical or oil spills, or sudden changes in salinity. For example, a peak monsoonal rainfall in 2001 in Cairns, Australia, lowered salinities in the region's largest marina to as low as 11 psu, resulting in the sudden mortality of 95 % of all biofouling assemblages within the marina (Floerl 2002; also see Rajagopal et al. 1997). Experimental exposure of biofouling assemblages to higher-than-normal concentrations of copper have been shown to result in significant levels of mortality in particular biofouling taxa and changes in community composition (Johnston and Keough 2000; Johnston et al. 2002; Johnston et al. 2003). Biofouling assemblages on vessel hulls residing in port or other coastal environments may be subject to similar types of disturbance, resulting in elevated mortality rates.

Table 4-1: Mortality rates of marine invertebrate taxa during the first 4 weeks following settlement. Estimates were derived via the weekly standardised survival rates calculated by Hunt and Scheibling (1997) and from estimates of cumulative morality presented in Gosselin and Qian (1997). other data were obtained from Stoner (1990), Hurlbut (1991) and Petersen and Svane (1995).

Time	Taxon	Cumulative mortality
Week 1	Barnacles	0 – 78%
	Bryozoa	1 – 6%
	Bivalves	15 – 20%
	Gastropods	23%
	Colonial ascidians	0 – 90%
	Solitary ascidians	13 – 43%
Week 2	Barnacles	0 – 75%
	Bryozoa	2 – 12%
	Bivalves	28 – 36%
	Gastropods	41%
	Colonial ascidians	0 -100%
	Solitary ascidians	24 – 68%
Week 3	Barnacles	0 – 88%
	Bryozoa	3 – 17%
	Bivalves	39 – 49%
	Gastropods	54%
	Colonial ascidians	0 – 100%
	Solitary ascidians	34 – 81%
Week 4	Barnacles	0 – 94%
	Bryozoa	4 – 22%
	Bivalves	48 – 59%
	Gastropods	24 – 99%
	Colonial ascidians	22 – 99%
	Solitary ascidians	43 – 89%

4.2 Mortality induced by vessel voyages

During vessel voyages, biofouling organisms are exposed to hydrodynamic drag that can have a significant effect on survival via dislodgement or inhibition of feeding. Typically, fast-moving vessels (> 15 knots) in regular use have relatively low levels of biofouling that are mostly confined to niche areas protected from voyage-induced drag. Slow-moving (< 5 knots) vessels, such as barges and many sailing yachts, are more likely to support biofouling assemblages that are more widespread across the submerged hull area (Foster and Willan 1979; James and Hayden 2000; Coutts and Taylor 2004; Davidson et al. 2008; Inglis et al. 2010). Coutts et al. (2009) tested the effect of vessel speed on biofouling assemblages up to 7 days following voyages of 20 minutes duration. They found that: (1) vessel speeds of 5 and 10 knots had little effect on biofouling species richness, but species richness decreased by 50% following voyages of 18 knots, (2) percentage biofouling cover decreased with increasing speed, with decreases most pronounced at 10 and 18 knots (percent cover

reduced by 24% and 85%, respectively), and (3) survival was greatest for biofouling organisms with colonial, encrusting, hard and/or flexible morphological characteristics, and this effect increased with speed. For example, solitary ascidians and sabellid worms had lower rates of survival than encrusting bryozoans, hydroids and arborescent bryozoans. Mean reduction in percentage cover of the solitary ascidian *Corella eumyota* was 100% at 18 knots, compared to 18 % for the colonial ascidian *Botryllus leachi*. However, whilst higher vessel speeds may reduce overall biofouling biomass and remove some organism types, they do not eliminate biofouling translocation risk, especially not for protected niche areas that are not exposed to drag.

A further source of mortality associated with vessel voyages is the passage through or into environments that are not within the physiological tolerance range of the biofouling organisms (Visscher 1928; Moran and Grant 1991). For example, transition into environments with different or higher contaminant levels can affect survival of biofouling organisms. Turner et al. (1997) reported substantial mortality and a change in assemblage composition when existing biofouling assemblages were translocated to different marina environments along putative gradients of contaminant and sedimentation levels. Similar results are reported by Moran and Grant (1991) and Mayer-Pinto and Junqueira (2003). Passages of vessels from marine to brackish or freshwater environments or from tropical to temperate seawater temperatures (and vice-versa) typically result in considerable biofouling mortality (Visscher 1928; Davidson et al. 2006). While faster vessel speeds may significantly affect the survival and growth of some biofouling organisms, there is also a converse risk that faster passage through unfavourable environments may reduce mortality of some biofouling organisms as they spend less time in conditions that are detrimental to them (Minchin and Gollasch 2003).

5 Summary and conclusions: Biofouling accumulation on vessel hulls

Our review of biofouling accumulation in temperate and tropical environments indicates that biofouling organisms can recruit to susceptible substrates following an immersion period of a single week. While none of the studies we reviewed examined recruitment to vessel hulls specifically, we expect that such short-term accumulation of biofouling is possible on hull surfaces lacking functional antifouling paint. These will most certainly include niche areas devoid of antifouling paint, such as propeller shafts, rudder shafts, bow thrusters and similar structures. Darbyson et al. (2009) found that colonization of untreated vessel hull materials by the solitary ascidian *Styela clava* was greater on bare aluminium substrates than on any other substrate examined, illustrating the susceptibility of common, unprotected hull materials to marine biofouling. Biofouling accumulation is also likely in locations where the antifouling paint is either too old or has been worn off by drag or abrasive/mechanical damage (Davidson et al. 2006; ASA 2007; Piola and Johnston 2008). However, it is important to emphasise that, in the studies we reviewed, recruitment did not occur consistently over very short (1-week) timeframes – at least not to organism sizes that were detected by the sampling methods used in the various studies. Biofouling accumulation became more consistent and, generally, attained higher densities, following immersion periods exceeding 1 week.

5.1 Seasonal variation in biofouling risk

The biofouling risk of vessels undergoing short residency periods is likely to vary geographically and seasonally, particularly in higher latitudes, where reproduction and settlement of biofouling organisms is highly seasonal (Coe 1932; Skerman 1958,1959; Richmond and Seed 1991; Watson and Barnes 2004; Holm et al. 2008). In contrast, biofouling risk is likely to be more consistent in many tropical environments, where recruitment of sessile species occurs more or less throughout the year, with the exception of periods of extreme monsoonal events (Richmond and Seed 1991; Floerl 2002; Swami and Udhayakumar 2010). Tropical marine environments may also possess greater biofouling diversity, and faster growth rates resulting in earlier maturity of biofouling species (Paul 1942; Richmond and Seed 1991; Holm et al.2008). For example, Rajagopal et al. (1997) found a maximum biofouling biomass accumulation of 64 kg m^{-2} within 30 days at a location in India, and Paul (1942), also working in India, observed sexual maturity in the serpulid *Hydroides norvegica* and the barnacle *Balanus amphirite* at 9 and 16 days after recruitment, respectively. Biofouling assemblages that colonized and developed on hull surfaces in tropical environments may thus pose a particularly high risk to potential recipient environments, insofar as these display similar environmental characteristics.

5.2 Influence of physical environment on biofouling risk

Rates of recruitment of biofouling organisms are likely to be highest in port environments, where there are extensive resident populations of biofouling species and where protective breakwalls often restrict exchange of water with surrounding coastal areas (Floerl and Inglis 2003; Dafforn et al. 2008). Some studies have also recorded greater rates of recruitment in polluted port environments compared to less polluted natural locations (e.g. Kocak et al. 1999), although experiments may have been confounded by the absence of sampling in unpolluted port environments. Many shipping environments possess a characteristic suite of

biofouling organisms that recruit with varying intensity depending on the time of year (Holm et al. 2008). Generally, as vessels reside for increasing periods in port and marina environments, they accumulate a greater proportion of the resident biofouling assemblage on their submerged hull surfaces (Floerl and Inglis 2005).

5.3 Biofouling accumulation on vessels following in-water or shore-based cleaning

There is some uncertainty regarding the performance of antifouling paints following manual removal of biofouling. Representatives of the antifouling paint industry frequently suggest that hull cleaning (e.g. using mechanical brushes) removes biofouling and the upper, hydrolysed layers of antifouling coatings and 'restores' the effectiveness of antifouling paints. This was not confirmed in experiments undertaken by Floerl et al. (2005) in tropical Australia, where surfaces coated in three contemporary antifouling paints were immersed in static conditions for 7 months until extensive biofouling assemblages had developed. These were then removed using a stiff brush. Recolonisation of cleaned surfaces occurred rapidly: after 2 weeks, an average of 3,000 recruits were present on manually cleaned surfaces (17 x 17 cm). The recruits included barnacles, bivalves, ascidians, bryozoans, hydroids, amphipods, tubeworms and sponges (Floerl et al. 2005). Lower biofouling rates on cleaned and sterilized surfaces suggested that the elevated recruitment occurred in response to traces of organic material remaining on surfaces that had been subjected to brush cleaning. A relevant real-world example is provided by a floating dry-dock towed to Pearl Harbor, Hawaii, by the U.S. Navy approximately 20 years ago. The dock had been cleaned by divers in Subic Bay, Philippines, but remained moored in Subic Bay for approximately 3-4 weeks prior to being towed to Hawaii. Translocation of the floating dock to Hawaii was followed by the localized appearance and subsequent expansion of two non-indigenous species (one sponge and one oyster) that are thought to have originated from the Philippines. It is probable that these species may have originated from the floating dock (M. Hadfield, pers. comm. 2010).

Some biofouling taxa are able to colonise surfaces coated in antifouling paints that still release biocidal compounds. A range of marine organisms exhibit tolerance to biocides such as copper and zinc and are able to colonise hull surfaces that retain some toxic properties (Dafforn et al. 2008; Piola et al. 2009). Such species can also act as non-toxic micro-substrates for less tolerant organisms that may colonise their upper surfaces (Floerl et al. 2004).

The literature consulted during our review suggests that the colonization of hull surfaces following in-water or shore-based cleaning is possible, for both non-toxic hull surfaces (not coated in antifouling paint or where paint is ineffectual) and for surfaces coated in antifouling paint that emit residual levels of biocides. Also here, biofouling risk is likely to be seasonal in temperate latitudes and more or less constant in the tropics. It is not possible from this review to predict the likelihood of biofouling accumulation within the first week following cleaning. However, depending on season and latitude, it is likely that residency periods of 2-4 weeks post-cleaning will result in the accumulation of a range of biofouling taxa that are available for transport to Australia. A proportion of these organisms will most likely perish from either natural (stochastic mortality, predation, rainfall) or anthropogenic influences (pollution) before the vessel leaves for Australia. Further mortality is likely to occur en route, depending on travel speed and duration – although mortality rates of young, recently recruited organisms may be lower than those reported by Coutts et al. (2009) who used

well-developed, mature assemblages for their experiments. Yet, the importance marine biosecurity has attained as an environmental and economic issue in recent times is testament to the fact that a significant proportion of biofouling organisms are likely to survive the transfer and arrive at their destination intact and able to reach a reproductive state.

6 Identification of biofouling organisms during the first 4 weeks following settlement

In this section we provide an assessment of whether recruits of a range of target species (identified by the Commonwealth Government as posing a moderate, high or extreme biosecurity risk to Australia) can be identified by trained field personnel or recognized taxonomic specialists during the first 4 weeks following settlement to a hull surface. We do not comment on the sensitivity of dive or camera surveys to *detect* these recruits at 1-4 weeks of age. Instead we assume that a recruit has been found and comment on whether the specimen could be *identified* by either a field officer or taxonomic specialist. Our assessment assumes that a field officer will not have access to a high-powered microscope. Following this assessment we provide some basic notes on the size of biofouling taxa 1-4 weeks following settlement and a description of the morphological features that are commonly used during the identification process.

6.1 Ability to identify biofouling recruits at ages 1 – 4 weeks

An evaluation of the ease with which recruits of 1-4 weeks of age can be identified is provided in Table 5. All species listed in this table are able to recruit in both temperate and tropical environments and our estimates of ability of identification are based on average growth rates reported in the literature. Due to the higher growth rates that most species achieve in warmer waters, an observer may generally be able to identify a particular organism to a given taxonomic level approximately 1 week earlier in warm tropical environments than described in Table 6-1 (containing estimates for temperate environments). Notable exceptions in Table 6-1 are the barnacle *Balanus improvisus* and the green alga *Ulva pertusa*, for which optimal growth occurs in temperate environments and where identification will not occur faster in the tropics. Generally, it is unlikely that field officers with a good working knowledge of biofouling groups would be able to identify recruits beyond phylum level until they are at least 4 weeks old, unless they received extensive training in the identification of early recruits of the particular target species. Even trained taxonomists may not be able to identify some 2-week old recruits beyond phylum level, and most 3-week old recruits beyond family level. Of the 31 taxa presented in Table 6-1**,** the taxonomic specialists we consulted estimated they may be able to identify - 4 weeks after settlement - three species to genus level, 13 species to family or possibly genus level, and 15 species to phylum or possibly family level.

6.2 Notes on the identification of biofouling taxa

6.2.1 Annelida

Annelid worms found on vessel hulls are either errant (free living, non-tube dwelling) or sedentary (living in a permanently attached tube). Most polychaetes have separate sexes

Table 6-1: The likely ability of (1) a trained field officer (FO) and (2) a recognised taxonomic specialist (TS) to identify newly settled recruits of a range of biofouling taxa between 1-4 weeks post settlement. Crosses (X) indicate no identification can be made even to phylum level. Ticks (√) indicate that identification is possible and letters following the ticks suggest a level to which identification is most likely limited. P: phylum level only (e.g. bryozoans, crabs, sponges); F: family level or higher (e.g. sabellid polychaete, sessile barnacle, bivalve, gastropod); G, genus level. Note that all species are able to recruit in both temperate and tropical environments. Data provided in this table are based on recruitment in temperate latitudes and assume optimal environmental conditions. **With the exception of *B. improvisus* and *U. pertusa*, identification to a given taxonomic level can occur 1 week earlier if a vessel is moored in warm tropical waters.**

Taxon	Description (family or growth form)	Example	Risk rank	Source	Week1		Week 2		Week 3		Week 4	
					FO	TS	FO	TS	FO	TS	FO	TS
Phylum	Sabellidae – fan/feather cluster worms	*Sabella spallanzanii*		MAFBNZ/ NIMPIS	X	X	√P	√P	√P	√FG	√F	√G
Annelida	Serpulidae – tube worms	*Hydroides dianthus*	M	DAFF	X	√P	X	√P	√P	√PF	√P	√F
	Spirorbidae – spiral tube worm	No specific example			X	√P	X	√P	√P	√PF	√P	√F
	Errant, free living, non-sedentary	*Polydora nuchalis*	H	DAFF	X	X	X	√P	X	√P	√P	√PF
Porifera	Free standing	No specific example			X	√P	X	√P	X	√PF	X	√FG
	Encrusting	*Cliona thoosina*	E	DAFF	X	√P	X	√P	X	√PF	X	√FG
	Thick mat	*Gelliodes fibrosa*	M	DAFF	X	√P	X	√P	X	√PF	X	√FG
Bryozoa	Erect/branching	Amathia distans		NIMPIS	X	√P	X	√PF	√P	√FG	√P	√G
	Encrusting Mytiloida, Veneroida	*Schizoporella unicornis*		NIMPIS	X	√P	X	√PF	√P	√FG	√P	√G
Mollusca	Dreissenidae – mussels	*Perna perna*	E	DAFF	X	X	X	X	X	√P	√P	√PF
		Perna viridis	E	DAFF	X	X	X	X	X	√P	√P	√PF
		Brachidontes variabilis	E	DAFF	X	X	X	X	X	√P	√P	√PF
		Dreissena bugensis	E	DAFF	X	X	X	X	X	√P	√P	√PF
		Dreissena polymorpha	E	DAFF	X	X	X	X	X	√P	√P	√PF
		Limnoperna fortune	E	DAFF	X	X	X	X	X	√P	√P	√PF
		Mytilopsis leucophaeta	E	DAFF	X	X	X	X	X	√P	√P	√PF
	Ostreidae – oysters	*Crassostrea virginica*	E	DAFF	X	√P	X	√P	X	√PF	√P	√PF

Taxon	Description (family or growth form)	Example	Risk rank	Source	Week1		Week 2		Week 3		Week 4	
					FO	TS	FO	TS	FO	TS	FO	TS
	Gastropoda – sea snails	*Crepidula fornicate*	E	DAFF	X	X	X	√P	X	√P	√P	√PF
Arthropoda	Decapoda – crabs	*Eriocheir sinsnsis*	E	DAFF	X	X	X	X	X	√P	X	√P
		Charybdis japonica	E	DAFF	X	X	X	X	X	√P	X	√PF
		Hemigrapsus sanguineus	E	DAFF	X	X	X	X	X	√P	X	√PF
		Rhithrpanopeus harrisi	E	DAFF	X	X	X	X	X	√P	X	√PF
	Pedunculata – goose/stalked barnacles	No specific example			X	√P	X	√P	√P	√PF	√P	√FG
	Sessilia – acorn barnacles	*Balanus eburneus*	E	DAFF	X	√P	X	√P	√P	√PF	√P	√FG
		Balanus improvises	E	DAFF	X	√P	X	√P	√P	√PF	√P	√FG
Chlorophyta	Green algae	*Ulva pertusa*	E	DAFF	X	X	X	√P	√P	√PF	√P	√FG
Rhodophyta	Red algae	No specific example			X	X	X	√P	√P	√PF	√P	√FG
Phaeophyceae	Brown algae	*Sargassum mutucum*	E	DAFF	X	X	X	√P	√P	√PF	√P	√FG
Chordata	Colonial ascidian	*Didemnum vexillum*	E	DAFF	X	√P	X	√PF	X	√FG	X	√FG
	Solitary ascidian	*Styela clava*		MAFBNZ	X	√P	X	√P	X	√PF	X	√FG
Cnidaria	Hydrozoa – hydroids	*Obelia dichotoma*		NIMPIS	X	√P	X	√P	X	√PF	X	√FG

and shed mature gametes into the water column where they are fertilised and float as larvae in the plankton. Eventually they metamorphose into the adult form by adding segments, and settle onto suitable substrates.

Key diagnostic features used to identify polychaetes vary between groups. In general, chaetae (chitinous bristles/hairs), head structures and tube morphology are characteristic. In a lot of species, however, these features are not diagnostic until approximately 2-3 months old. Under optimal growth conditions, sabellid polychaetes could attain 2-4 mm length (approx 0.1 mm diameter) within 3-4 weeks following settlement, with segmentation and chaetae faintly visible. Some development of the head appendages is likely. The tubes of sabellids 1-4 weeks following settlement are likely to resemble a clear, mucous tube if on a clean, hard hull surface. Some species may incorporate sand grains or debris into the tube surface. In sabellid worms, the colour, chaetae and radiole morphology (feather-like tentacle found on the crown structure on the head), presence of eyes on radioles and segments, and the colour structure are key features. However, it is unlikely that these features are fully developed 4 weeks following settlement, particularly in temperate environments. In *Sabella spallanzanii*, for example, the colour pattern, morphology and arrangement of radioles is particularly diagnostic. However, these features would not be fully developed between 1-4 weeks following settlement in either temperate or tropical environments.

Tube growth (calcium carbonate) in some species of serpulid polychaetes can be extremely rapid, particularly in the tropics. In spirorbine serpulids the operculum, tube ornamentations and brooding structures are used to identify species. However, these are probably not distinct until the adult stage and identification is difficult even then. Operculum morphology is diagnostic for the serpulid worm *Hydroides dianthus*, but tube morphology is used to identify most other serpulids

For the errant polychaete *Polydora nuchalis*, chaetiger (segment) spines, head structures and pygidium (posterior segment) are diagnostic features. Like the other species though, these features are unlikely to be developed or discernable at 4 weeks following settlement, neither in temperate nor tropical latitudes.

Polychaetes (at least the tubes) could be identifiable to phylum level by a field officer 2 weeks following settlement. For a trained taxonomist, some polychaetes are identifiable to family level at week 1, particularly in the tropics. Some species could be identifiable to genus or species level by week 4, depending on the development of key diagnostic features. The removal of soft bodied specimens or fragile tubes from hull surfaces may cause damage, resulting in reduced ease and likelihood of correct identification.

6.2.2 Porifera

Sponges are multi-celled animals with water intake and outlet openings connected by chambers. True skeletons are absent but calcareous or siliceous crystalline spicules, often combined with coarse collagen fibres (spongin), provide a characteristic support network. Sponges contain canals and complex cellular structures that provide habitats for a variety of other organisms. Sponges are known for regenerating from broken fragments. Some species reproduce via budding but most sponges reproduce sexually. Sponge larvae have a short planktonic phase lasting one to several days. Generally larvae are negatively phototaxic, so the darkened surfaces of a vessel hull are ideal settlement areas. The mode and timing of

reproduction and subsequent growth rates of sponges vary between species. Some species are capable of sexual reproduction when only a few weeks old.

Key diagnostic features for sponge identification include the presence/absence and shape of spicules, colony colour and appearance (i.e. growth form) and cellular morphology. For both *Cliona thoosina* (an encrusting boring sponge) and *Gelliodes fibrosa* (thick mat form), siliceous spicules would be present but not fully developed 4 weeks following settlement. *C. thoosina* recruits might resemble tiny spherical disks (possibly 1-2 cm diameter), and may have raised sections with apical oscule (hole) in what might be a transparent membrane. Species from the genus *Cliona* are known as sulphur sponges and are typically bright yellow in colour. *G. fibrosa* recruits resemble a furry encrustation of a translucent tent-like structure. However, whether the recruits achieve sufficient growth in 1-4 weeks to bear these characters depends on environmental and physical conditions. It is possible in tropical environments that diagnostic characters will have developed in *G. fibrosa* in this time.

It is unlikely that a technical officer/diver could recognize early sponge recruits on a ship hull, even at 4 weeks. Recruit form is not well defined and could quite easily be mistaken for a bryozoan, thick biofilm or algae. It may be possible for a taxonomist to identify an older recruit (i.e. 3-4 weeks following settlement), but it is extremely difficult to differentiate new sponge recruits from bryozoans and didemnid ascidians. As with many other hull fouling taxa, removal from the hull surface will render newly recruited sponges unidentifiable, even to a taxonomist.

6.2.3 Bryzoans

Bryozoans are colonial organisms that form encrusting or tufting aggregations on solid substrates, including vessel hulls. Encrusting colonies form thin, flat, circular or irregular patches, which often resemble sponges. Erect bryozoans form folds, tufts or bushy structures, which may be mistaken for hydroids or small seaweeds. All bryozoans are comprised of box-like or tube-like units (zooids).

Upon settlement, a fertilised bryozoan egg attaches to a substrate and metamorphoses into the first zooid of the colony, the ancestrula. The ancestrula buds off one or more daughter zooids, and the colony grows. The time taken for zooid budding and formation depends on environmental and physical conditions. Key diagnostic features for bryozoans appear once the species has developed past the ancestrula. In many bryozoans, enough characteristics are present from this developmental point onwards for identification by a taxonomist to genus or even species level. For many other species, however, examination of the reproductive stages is necessary for identification. These features do not usually appear until the colony is more than 1-2 cm in diameter or height, which would require longer than 4 weeks to attain even in optimum environmental conditions.

Ctenostomes (e.g. species of *Amathia*, *Bowerbankia* and *Zoobotryon*) are uncalcified and partially transparent, so would be very difficult to see unless present on a clean substratum. At 1-4 weeks only a taxonomist would be able to identify these species. For encrusting forms like *Schizoporella unicornis*, it is possible that colonies will be visible and have potentially attained a size of 7-8 cm in diameter after 3-4 weeks. The same is true for most encrusting, coloured bryozoan species. Erect forms might have attained a height of several cm after a month.

A field officer may be able to identify a bryozoan colony to at least phylum level by week 3-4, depending on the rate of growth and growth form of the colony. A field officer might be able to discern an encrusting or tufting/branching bryozoan colony from a hull fouling assemblage 3-4 weeks following settlement. A taxonomist should be able to identify most bryozoan species to genus, possibly species level by week 3-4. In tropical environments, where growth rates are generally faster, some species may be identified at an age of 2 weeks.

6.2.4 Molluscs

Molluscs such as mussels, oysters and sea snails are common taxa found in hull fouling assemblages. Most species spawn eggs and sperm into the water column, where fertilisation and larval development take place. Some species, however, exude fertilised egg masses that develop into larvae. The larvae settle onto suitable substrates and metamorphose into a juvenile stage (similar in appearance to adults but the organs are not fully developed). Mussels are identifiable by shell characteristics such as shape, hinge location and hinge line proportions, and location of adductor mussel attachments/scars on the inside of the shell.

Oyster shells may be colonised by many other marine species, increasing the surface area of available habitats on a vessel hull. Reproduction is similar to that of mussels whereby adults undergo broadcast spawning of eggs and sperm, followed by external fertlisation and development of free-swimming larvae. Larvae settle onto suitable substrates and metamorphose into juveniles (spat). Oyster spat can reach approximately 25 mm long in some species, such as *Crassostrea virginica*. Early spat (1-2 weeks old) are likely to be transparent and not easily identifiable to genus or species level. Once the shells have thickened and cemented to the hull, juvenile oysters become easier to identify.

Fertilisation is also an external process for some gastropods (including *Crepidula fornicata*, commonly known as the slipper shell), producing larvae that settle out of the water column. *C. fornicata* is a rapid growing, suspension feeding gastropod. The diagnostic features of gastropods include shell shape and markings. It is unlikely that by 4 weeks following settlement, *C. fornicata* will have developed a characteristic shell shape. It is unlikely that this gastropod will be identifiable during early stages (weeks 1-3).

It is unlikely that a trained field officer would be able to recognise early (week 1-2) mollusc recruits. Typically spat are transparent, tiny and extremely difficult to identify. Three to 4 weeks following settlement, a field officer may achieve identification to phylum level, while identification to family level may be achieved by a taxonomic expert. Juvenile bivalves are extremely likely to be damaged and fragmented when removed from a hull using scraping tools.

6.2.5 Arthropoda – crabs and barnacles

Crab larvae (zoea and megalopa stages) are free living in the water column. They settle onto a suitable habitat and develop into juvenile crabs. Identifiable characteristics of crabs include general external morphology (i.e. carapace, spines or appendage shapes/armature). Crabs are unlikely to be identified at an age of 1-4 weeks following settlement, neither in temperate or tropical environments. Most species will not be large enough to be detected, and transparency or camouflage may hinder detection of some species. A trained

taxonomist may be able to identify some crab species around week 4, but most likely not beyond family level. Many juvenile crab species look similar at such a small size.

Barnacles are sessile suspension feeders, attached permanently to hard substrates. The shells of sessile (acorn) barnacles grow directly on the substrate, whereas pedunculate (goose) barnacles attach to the substrate by means of a stalk. Barnacles are one of the most common and successful hull fouling taxa. Many species are able to overwhelm competitors and monopolise space by producing vast numbers of fast-growing offspring that settle and cover (swamp) substrates.

Barnacles such as *Balanus ebernus* and *B. improvisus* are identifiable by external and internal plate morphology, the operculum (the covering of the apex of the ring of plates), and thoracic and abdominal characteristics.

Barnacles are likely to be identified to phylum level by a field officer at approximately 2-4 weeks following settlement. A trained taxonomist will most likely be able to identify barnacles to family or genus level by weeks 3-4. However, juvenile barnacles frequently become damaged beyond identification when removed from vessel hulls using scraping tools.

6.2.6 Algae

Algae are a large and diverse group, with a range of morphologies and forms. The three main phyla are Rhodophyta (red), Chlorophyta (green) and Heterokontophyta (which includes brown). Life cycles may be complex and considerably vary between taxa. In general there is an asexual phase, a sexual phase and fusion of male and female gametes.

Identification of algae is dependent on the taxa. For some taxa, the early germination/settlement stage is highly distinctive. For others, the early stages are almost indistinguishable and are incorporated in a general biofilm. Fast growing taxa, particularly those in tropical environments and with a distinctive germination stage, will be conspicuous to a trained field officer by week 3. For a trained taxonomist, the same level of identification is likely. A few taxa could be identified to family level, possibly genus by week 4. Others would require further development/growth to occur before they could be distinguished. Pioneer species such as green filamentous algae (often *Enteromorpha* spp.), are normally identifiable within a couple of weeks after settlement.

6.2.7 Chordata

Ascidians are sessile, filter feeding organisms that are characterized by two openings (siphons) on the upper surface for inhalant and exhalent water. Forms include solitary individuals, social clumps (communities of individuals clumped and attached at the base) and colonies (many individual units (zooids) forming colonial masses). The body is comprised of three regions; the pharyngeal region (containing the pharynx), the abdomen and the post abdomen (containing the heart and gonads). Development of the internal organs is necessary for species identification.

Solitary ascidian larva are generally fertilised externally and settle on appropriate surfaces, secrete an adhesive for attachment and begin to metamorphose. Organ and feeding apparatus development follows and some ascidians can reach sexual maturity in a few weeks.

Colonial ascidians can reproduce both asexually (via budding) and sexually. Sexual reproduction involves the release of larvae, which settle onto substrates and begin to divide into genetically identical zooids. Other species reproduce asexually by budding or fission. The family Didemnidae essentially splits in two, with the pharynx growing a new digestive tract and the original digestive tract growing a new pharynx.

It is not likely that a field officer would be able to identify colonial or solitary ascidians between 1-4 weeks following settlement. Early recruits are likely to be confused with a sponge. A major concern for the identification of ascidians is damage to soft bodied species via removal of material from a vessel hull. A taxonomist would be able to identify a young recruit (i.e. 2-4 weeks) *in situ* and, if not damaged, from a hull scraping sample. To determine the species of solitary ascidian recruits, such as *Styela clava*, dissection and examination of intact internal structures such as the gut, branchial sac and gonad is required. This process requires a high level of expertise, particularly for species not known in Australia. The other main consideration is that a 4 week old recruit may not be sexually mature, in which case gonad structure cannot be used as a character for species identification. Identification of colonial ascidians such as *Didemnum vexillum* depends on whether the colony has started to divide, and whether mature zooids are present.

A field officer may not be likely to be able to identify colonial ascidians reliably at any stage. For a taxonomist, some colonial ascidians may be identifiable to family or genus level at 2-3 weeks assuming division into zooids. For solitary ascidians, depending on sexual maturity and growth rate, identification to family or genus may be possible for some species at 3-4 weeks post settlement.

6.2.8 Cnidaria - Hydroids

Hydroids are a class of small predatory animals that are typically colonial in form, although some species are solitary. Colonial hydroids are comprised of multiple tiny polyps connected together. Depending on the species, the hydroid may have a tree-like or fan-like appearance. Hydroids have specialised polyps for feeding and reproduction and, in some species, defence or floating devices. These polyps are key diagnostic features for the identification of the hydroid. The hyroid *Obelia* produces medusae (larvae) that reproduce sexually, releasing sperm and eggs. Fertilised eggs form zygotes, which develop into planula larvae. Planulae eventually settle onto a solid surface where they begin their reproductive phase of life. Once attached, a planula grows quickly and develops into one feeding polyp, subsequently developing branches of other feeding individuals.

It is unlikely that a trained field officer could identify a hydroid at 4 weeks following settlement. Hydroids are often mistaken for filamentous algae and other small branching organisms like bryozoans. Assuming differentiated polyps had developed on a 4 week old recruit, a taxonomist is likely to be able to identify a specimen to genus or possibly species level.

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Appendix A

Table A1: Short-term (≤ 4 weeks) biofouling accumulation (presence (✓) or absence (X)) to non-toxic surfaces in temperate marine environments on a per week basis. Where cells are blank, this indicates that either sampling was not conducted at that time or that presence/absence was not indicated. ? = uncertain (i.e. insufficient taxon differentiation or presence recorded in study but no specific details as to particular time of recruitment in biofouling). PVC = polyvinyl chloride, ABS = acrylonitrile butadiene styrene

Taxon	Week 1	Week 2	Week 3	Week 4	Substrate	Reference
Macroalgae	X	X			Unspecified	Visscher (1928)
		X		✓	Glass/Aluminium	Scheer (1945)
				✓	Perspex	Skerman (1958)
				X	Perspex	Skerman (1959)
				X	Asbestos	Chalmer (1982)
	X	X	X	X	Acrylic	Otsuka & Dauer (1982)
				✓	Polystyrene	El-Komi (1991)
		X		X	PVC	Nandakumar *et al.* (1993)
	X	X	?	X	Perspex	Henrikson & Pawlik (1995)
				✓	Ceramic	Fairfull & Harriott (1999)
		X		X	PVC	Johnston & Keough (2000)
				✓	Plexiglass	Berntsson & Jonsson (2003)
	X				PVC	Bullard *et al.* (2004)
				✓	Slate	Watson & Barnes (2004)
				✓	Polystyrene	Ramadan *et al.* (2006)
				X	ABS	Boyle *et al.* (2007)
	X	✓	✓	✓	PVC	Dziubińska & Janas (2007)
				✓	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
				X	Concrete and steel	Andersson *et al.* (2009)
Hydroids	✓	✓			Unspecified	Visscher (1928)
		X		✓	Glass/Aluminium	Scheer (1945)
				✓	Perspex	Skerman (1958)
				✓	Perspex	Skerman (1959)
				X	Asbestos	Chalmer (1982)
	X	X	X	✓	Acrylic	Otsuka & Dauer (1982)
				✓	Polystyrene	El-Komi (1991)
		X		X	PVC	Nandakumar *et al.* (1993)
	X	X	?	✓	Perspex	Henrikson & Pawlik (1995)
				X	Ceramic	Fairfull & Harriott (1999)
		X		X	PVC	Johnston & Keough (2000)
				✓	Plexiglass	Berntsson & Jonsson (2003)
	X				PVC	Bullard *et al.* (2004)
				✓	Slate	Watson & Barnes (2004)
				✓	Polystyrene	Ramadan *et al.* (2006)
				✓	ABS	Boyle *et al.* (2007)
	X	X	X	X	PVC	Dziubińska & Janas (2007)
				✓	PVC (+ anticorrosive	Holm *et al.* (2008)

Taxon	Week 1	Week 2	Week 3	Week 4	Substrate	Reference
					paint)	
				✓	Concrete and steel	Andersson *et al.* (2009)
Anenomes	X	X			Unspecified	Visscher (1928)
		X		X	Glass/Aluminium	Scheer (1945)
				X	Perspex	Skerman (1958)
				X	Perspex	Skerman (1959)
				X	Asbestos	Chalmer (1982)
	X	X	X	X	Acrylic	Otsuka & Dauer (1982)
				X	Polystyrene	El-Komi (1991)
		X		X	PVC	Nandakumar *et al.* (1993)
	X	X	?	X	Perspex	Henrikson & Pawlik (1995)
				X	Ceramic	Fairfull & Harriott (1999)
		X		X	PVC	Johnston & Keough (2000)
				✓	Plexiglass	Berntsson & Jonsson (2003)
	X				PVC	Bullard *et al.* (2004)
				✓	Slate	Watson & Barnes (2004)
				X	Polystyrene	Ramadan *et al.* (2006)
				X	ABS	Boyle *et al.* (2007)
	X	X	X	X	PVC	Dziubińska & Janas (2007)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
				X	Concrete and steel	Andersson *et al.* (2009)
Scyophozoans	X	X			Unspecified	Visscher (1928)
		X		X	Glass/Aluminium	Scheer (1945)
				X	Perspex	Skerman (1958)
				X	Perspex	Skerman (1959)
				X	Asbestos	Chalmer (1982)
	X	X	X	✓	Acrylic	Otsuka & Dauer (1982)
				X	Polystyrene	El-Komi (1991)
		X		X	PVC	Nandakumar *et al.* (1993)
	X	X	?	X	Perspex	Henrikson & Pawlik (1995)
				X	Ceramic	Fairfull & Harriott (1999)
		✓		✓	PVC	Johnston & Keough (2000)
				X	Plexiglass	Berntsson & Jonsson (2003)
	X				PVC	Bullard *et al.* (2004)
				X	Slate	Watson & Barnes (2004)
				X	Polystyrene	Ramadan *et al.* (2006)
				X	ABS	Boyle *et al.* (2007)
	X	X	X	X	PVC	Dziubińska & Janas (2007)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
				X	Concrete and steel	Andersson *et al.* (2009)
Bryozoans - encrusting	X	X			Unspecified	Visscher (1928)
		✓		✓	Glass/Aluminium	Scheer (1945)
				✓	Perspex	Skerman (1958)
				X	Perspex	Skerman (1959)
				✓	Asbestos	Chalmer (1982)
	X	X	X	X	Acrylic	Otsuka & Dauer (1982)
				✓	Polystyrene	El-Komi (1991)

Taxon	Week 1	Week 2	Week 3	Week 4	Substrate	Reference
		✓		✓	PVC	Nandakumar *et al.* (1993)
	X	X	?	✓	Perspex	Henrikson & Pawlik (1995)
				✓	Ceramic	Fairfull & Harriott (1999)
		✓		✓	PVC	Johnston & Keough (2000)
				✓	Plexiglass	Berntsson & Jonsson (2003)
	✓				PVC	Bullard *et al.* (2004)
				✓	Slate	Watson & Barnes (2004)
				✓	Polystyrene	Ramadan *et al.* (2006)
				✓	ABS	Boyle *et al.* (2007)
	X	X	X	X	PVC	Dziubińska & Janas (2007)
				✓	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
				✓	Concrete and steel	Andersson *et al.* (2009)
Bryozoans - arborescent	X	X			Unspecified	Visscher (1928)
		✓		✓	Glass/Aluminium	Scheer (1945)
				✓	Perspex	Skerman (1958)
				✓	Perspex	Skerman (1959)
				X	Asbestos	Chalmer (1982)
	X	X	X	✓	Acrylic	Otsuka & Dauer (1982)
				✓	Polystyrene	El-Komi (1991)
		X		X	PVC	Nandakumar *et al.* (1993)
	X	X	?	✓	Perspex	Henrikson & Pawlik (1995)
				?	Ceramic	Fairfull & Harriott (1999)
		✓		✓	PVC	Johnston & Keough (2000)
				X	Plexiglass	Berntsson & Jonsson (2003)
	X				PVC	Bullard *et al.* (2004)
				✓	Slate	Watson & Barnes (2004)
				✓	Polystyrene	Ramadan *et al.* (2006)
				✓	ABS	Boyle *et al.* (2007)
	X	X	X	X	PVC	Dziubińska & Janas (2007)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
				X	Concrete and steel	Andersson *et al.* (2009)
Barnacles	✓	✓			Unspecified	Visscher (1928)
		X		✓	Glass/Aluminium	Scheer (1945)
				✓	Perspex	Skerman (1958)
				✓	Perspex	Skerman (1959)
				✓	Asbestos	Chalmer (1982)
	X	X	X	✓	Acrylic	Otsuka & Dauer (1982)
				✓	Polystyrene	El-Komi (1991)
		✓		✓	PVC	Nandakumar *et al.* (1993)
	X	X	?	✓	Perspex	Henrikson & Pawlik (1995)
				✓	Ceramic	Fairfull & Harriott (1999)
		✓		✓	PVC	Johnston & Keough (2000)

Taxon	Week 1	Week 2	Week 3	Week 4	Substrate	Reference
				✓	Plexiglass	Berntsson & Jonsson (2003)
	X				PVC	Bullard *et al.* (2004)
				✓	Slate	Watson & Barnes (2004)
				✓	Polystyrene	Ramadan *et al.* (2006)
				✓	ABS	Boyle *et al.* (2007)
	X	X	X	X	PVC	Dziubińska & Janas (2007)
				✓	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
				✓	Concrete and steel	Andersson *et al.* (2009)
Nematodes	X	X			Unspecified	Visscher (1928)
		X		X	Glass/Aluminium	Scheer (1945)
				X	Perspex	Skerman (1958)
				X	Perspex	Skerman (1959)
				X	Asbestos	Chalmer (1982)
	X	X	X	X	Acrylic	Otsuka & Dauer (1982)
				X	Polystyrene	El-Komi (1991)
		X		X	PVC	Nandakumar *et al.* (1993)
	X	X	?	X	Perspex	Henrikson & Pawlik (1995)
				X	Ceramic	Fairfull & Harriott (1999)
		X		X	PVC	Johnston & Keough (2000)
				X	Plexiglass	Berntsson & Jonsson (2003)
	X				PVC	Bullard *et al.* (2004)
				X	Slate	Watson & Barnes (2004)
				X	Polystyrene	Ramadan *et al.* (2006)
				X	ABS	Boyle *et al.* (2007)
	X	X	X	X	PVC	Dziubińska & Janas (2007)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
				✓	Concrete and steel	Andersson *et al.* (2009)
Calcareous tube-forming polychaetes	X	X			Unspecified	Visscher (1928)
		✓		✓	Glass/Aluminium	Scheer (1945)
				✓	Perspex	Skerman (1958)
				✓	Perspex	Skerman (1959)
				✓	Asbestos	Chalmer (1982)
	X	X	X	X	Acrylic	Otsuka & Dauer (1982)
				✓	Polystyrene	El-Komi (1991)
		✓		✓	PVC	Nandakumar *et al.* (1993)
	X	X	?	✓	Perspex	Henrikson & Pawlik (1995)
				✓	Ceramic	Fairfull & Harriott (1999)
		✓		✓	PVC	Johnston & Keough (2000)
				X	Plexiglass	Berntsson & Jonsson (2003)
	✓				PVC	Bullard *et al.* (2004)
				✓	Slate	Watson & Barnes (2004)
				✓	Polystyrene	Ramadan *et al.* (2006)
				X	ABS	Boyle *et al.* (2007)
	X	X	X	X	PVC	Dziubińska & Janas (2007)
				X	PVC (+ anticorrosive	Holm *et al.* (2008)

Taxon	Week 1	Week 2	Week 3	Week 4	Substrate	Reference
					paint)	
				X	Concrete and steel	Andersson *et al.* (2009)
Sedimentary tube-forming polychaetes	X	X			Unspecified	Visscher (1928)
		X		X	Glass/Aluminium	Scheer (1945)
				X	Perspex	Skerman (1958)
				X	Perspex	Skerman (1959)
				X	Asbestos	Chalmer (1982)
	X	X	X	✓	Acrylic	Otsuka & Dauer (1982)
				X	Polystyrene	El-Komi (1991)
		X		X	PVC	Nandakumar *et al.* (1993)
	X	X	?	X	Perspex	Henrikson & Pawlik (1995)
				X	Ceramic	Fairfull & Harriott (1999)
		✓		✓	PVC	Johnston & Keough (2000)
				X	Plexiglass	Berntsson & Jonsson (2003)
	X				PVC	Bullard *et al.* (2004)
				X	Slate	Watson & Barnes (2004)
				X	Polystyrene	Ramadan *et al.* (2006)
				X	ABS	Boyle *et al.* (2007)
	X	X	X	X	PVC	Dziubińska & Janas (2007)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
				X	Concrete and steel	Andersson *et al.* (2009)
Errant polychaetes	X	X			Unspecified	Visscher (1928)
		X		✓	Glass/Aluminium	Scheer (1945)
				X	Perspex	Skerman (1958)
				X	Perspex	Skerman (1959)
				X	Asbestos	Chalmer (1982)
	X	X	X	X	Acrylic	Otsuka & Dauer (1982)
				✓	Polystyrene	El-Komi (1991)
		X		X	PVC	Nandakumar *et al.* (1993)
	X	X	?	X	Perspex	Henrikson & Pawlik (1995)
				X	Ceramic	Fairfull & Harriott (1999)
		X		X	PVC	Johnston & Keough (2000)
				X	Plexiglass	Berntsson & Jonsson (2003)
	X				PVC	Bullard *et al.* (2004)
				X	Slate	Watson & Barnes (2004)
				✓	Polystyrene	Ramadan *et al.* (2006)
				X	ABS	Boyle *et al.* (2007)
	X	X	X	X	PVC	Dziubińska & Janas (2007)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
				X	Concrete and steel	Andersson *et al.* (2009)
Isopods	X	X			Unspecified	Visscher (1928)
		X		X	Glass/Aluminium	Scheer (1945)
				X	Perspex	Skerman (1958)
				X	Perspex	Skerman (1959)
				X	Asbestos	Chalmer (1982)
	X	X	X	X	Acrylic	Otsuka & Dauer (1982)
				✓	Polystyrene	El-Komi (1991)
		X		X	PVC	Nandakumar *et al.*

Taxon	Week 1	Week 2	Week 3	Week 4	Substrate	Reference
						(1993)
	X	X	?	X	Perspex	Henrikson & Pawlik (1995)
				X	Ceramic	Fairfull & Harriott (1999)
		X		X	PVC	Johnston & Keough (2000)
				X	Plexiglass	Berntsson & Jonsson (2003)
	X				PVC	Bullard *et al.* (2004)
				X	Slate	Watson & Barnes (2004)
				✓	Polystyrene	Ramadan *et al.* (2006)
				X	ABS	Boyle *et al.* (2007)
	X	X	X	X	PVC	Dziubińska & Janas (2007)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
				X	Concrete and steel	Andersson *et al.* (2009)
Amphipods	X	X			Unspecified	Visscher (1928)
		X		✓	Glass/Aluminium	Scheer (1945)
				X	Perspex	Skerman (1958)
				X	Perspex	Skerman (1959)
				X	Asbestos	Chalmer (1982)
	X	X	X	X	Acrylic	Otsuka & Dauer (1982)
				✓	Polystyrene	El-Komi (1991)
		X		X	PVC	Nandakumar *et al.* (1993)
	X	X	?	X	Perspex	Henrikson & Pawlik (1995)
				X	Ceramic	Fairfull & Harriott (1999)
		X		X	PVC	Johnston & Keough (2000)
				X	Plexiglass	Berntsson & Jonsson (2003)
	X				PVC	Bullard *et al.* (2004)
				✓	Slate	Watson & Barnes (2004)
				✓	Polystyrene	Ramadan *et al.* (2006)
				X	ABS	Boyle *et al.* (2007)
	X	X	X	X	PVC	Dziubińska & Janas (2007)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
				X	Concrete and steel	Andersson *et al.* (2009)
Crabs	X	X			Unspecified	Visscher (1928)
		X		X	Glass/Aluminium	Scheer (1945)
				X	Perspex	Skerman (1958)
				X	Perspex	Skerman (1959)
				X	Asbestos	Chalmer (1982)
	X	X	X	X	Acrylic	Otsuka & Dauer (1982)
				X	Polystyrene	El-Komi (1991)
		X		X	PVC	Nandakumar *et al.* (1993)
	X	X	?	X	Perspex	Henrikson & Pawlik (1995)
				X	Ceramic	Fairfull & Harriott (1999)
		X		X	PVC	Johnston & Keough (2000)
				X	Plexiglass	Berntsson & Jonsson (2003)
	X				PVC	Bullard *et al.* (2004)
				X	Slate	Watson & Barnes (2004)

Taxon	Week 1	Week 2	Week 3	Week 4	Substrate	Reference
				✓	Polystyrene	Ramadan *et al.* (2006)
				X	ABS	Boyle *et al.* (2007)
	X	X	X	X	PVC	Dziubińska & Janas (2007)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
				X	Concrete and steel	Andersson *et al.* (2009)
Bivalves	X	X			Unspecified	Visscher (1928)
		X		✓	Glass/Aluminium	Scheer (1945)
				✓	Perspex	Skerman (1958)
				✓	Perspex	Skerman (1959)
				✓	Asbestos	Chalmer (1982)
	X	X	X	X	Acrylic	Otsuka & Dauer (1982)
				X	Polystyrene	El-Komi (1991)
		X		X	PVC	Nandakumar *et al.* (1993)
	X	X	?	X	Perspex	Henrikson & Pawlik (1995)
				X	Ceramic	Fairfull & Harriott (1999)
		X		X	PVC	Johnston & Keough (2000)
				✓	Plexiglass	Berntsson & Jonsson (2003)
	X				PVC	Bullard *et al.* (2004)
				✓	Slate	Watson & Barnes (2004)
				✓	Polystyrene	Ramadan *et al.* (2006)
				X	ABS	Boyle *et al.* (2007)
	X	X	X	X	PVC	Dziubińska & Janas (2007)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
				X	Concrete and steel	Andersson *et al.* (2009)
Gastropods	X	X			Unspecified	Visscher (1928)
		X		X	Glass/Aluminium	Scheer (1945)
				X	Perspex	Skerman (1958)
				X	Perspex	Skerman (1959)
				X	Asbestos	Chalmer (1982)
	X	X	X	X	Acrylic	Otsuka & Dauer (1982)
				X	Polystyrene	El-Komi (1991)
		X		X	PVC	Nandakumar *et al.* (1993)
	X	X	?	X	Perspex	Henrikson & Pawlik (1995)
				✓	Ceramic	Fairfull & Harriott (1999)
		X		X	PVC	Johnston & Keough (2000)
				X	Plexiglass	Berntsson & Jonsson (2003)
	✓				PVC	Bullard *et al.* (2004)
				X	Slate	Watson & Barnes (2004)
				X	Polystyrene	Ramadan *et al.* (2006)
				X	ABS	Boyle *et al.* (2007)
	X	X	X	X	PVC	Dziubińska & Janas (2007)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
				X	Concrete and steel	Andersson *et al.* (2009)
Sponges	X	X			Unspecified	Visscher (1928)
		X		X	Glass/Aluminium	Scheer (1945)
				X	Perspex	Skerman (1958)
				X	Perspex	Skerman (1959)

Taxon	Week 1	Week 2	Week 3	Week 4	Substrate	Reference
				X	Asbestos	Chalmer (1982)
	X	X	X	X	Acrylic	Otsuka & Dauer (1982)
				X	Polystyrene	El-Komi (1991)
		X		X	PVC	Nandakumar *et al.* (1993)
	X	X	?	X	Perspex	Henrikson & Pawlik (1995)
				X	Ceramic	Fairfull & Harriott (1999)
		✓		✓	PVC	Johnston & Keough (2000)
				X	Plexiglass	Berntsson & Jonsson (2003)
	✓				PVC	Bullard *et al.* (2004)
				✓	Slate	Watson & Barnes (2004)
				X	Polystyrene	Ramadan *et al.* (2006)
				X	ABS	Boyle *et al.* (2007)
	X	X	X	X	PVC	Dziubińska & Janas (2007)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
				X	Concrete and steel	Andersson *et al.* (2009)
Colonial ascidians	X	X			Unspecified	Visscher (1928)
		X		X	Glass/Aluminium	Scheer (1945)
				✓	Perspex	Skerman (1958)
				✓	Perspex	Skerman (1959)
				X	Asbestos	Chalmer (1982)
	X	X	X	✓	Acrylic	Otsuka & Dauer (1982)
				✓	Polystyrene	El-Komi (1991)
		X		X	PVC	Nandakumar *et al.* (1993)
	X	X	?	X	Perspex	Henrikson & Pawlik (1995)
				✓	Ceramic	Fairfull & Harriott (1999)
		✓		✓	PVC	Johnston & Keough (2000)
				✓	Plexiglass	Berntsson & Jonsson (2003)
	X				PVC	Bullard *et al.* (2004)
				✓	Slate	Watson & Barnes (2004)
				X	Polystyrene	Ramadan *et al.* (2006)
				✓	ABS	Boyle *et al.* (2007)
	X	X	X	X	PVC	Dziubińska & Janas (2007)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
				X	Concrete and steel	Andersson *et al.* (2009)
Solitary ascidians	X	X			Unspecified	Visscher (1928)
		X		✓	Glass/Aluminium	Scheer (1945)
				✓	Perspex	Skerman (1958)
				✓	Perspex	Skerman (1959)
				X	Asbestos	Chalmer (1982)
	X	X	X	✓	Acrylic	Otsuka & Dauer (1982)
				X	Polystyrene	El-Komi (1991)
		X		X	PVC	Nandakumar *et al.* (1993)
	X	X	?	X	Perspex	Henrikson & Pawlik (1995)
				X	Ceramic	Fairfull & Harriott (1999)
		✓		✓	PVC	Johnston & Keough

Taxon	Week 1	Week 2	Week 3	Week 4	Substrate	Reference
						(2000)
				✓	Plexiglass	Berntsson & Jonsson (2003)
	✓				PVC	Bullard *et al.* (2004)
				X	Slate	Watson & Barnes (2004)
				✓	Polystyrene	Ramadan *et al.* (2006)
				✓	ABS	Boyle *et al.* (2007)
	X	X	X	X	PVC	Dziubińska & Janas (2007)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
				X	Concrete and steel	Andersson *et al.* (2009)

Table A2: Short-term (≤ 4 weeks) biofouling accumulation (presence (✓) or absence (X)) to non-toxic surfaces in temperate marine environments on a per week basis. Where cells are blank, this indicates that either sampling was not conducted at that time or that presence/absence was not indicated. ? = uncertain (i.e. insufficient taxon differentiation or presence recorded in study but no specific details as to particular time of recruitment in biofouling). PVC = polyvinyl chloride, ABS = acrylonitrile butadiene styrene

Taxon	Week 1	Week 2	Week 3	Week 4	Substrate	Reference
Macroalgae				X	Wood	Lee & Trott (1973)
	X	X	X	X	Glass	Low *et al.* (1991)
				X	Concrete	Rajagopal *et al.* (1997)
				?	Fibreglass (+ anticorrosive paint)	Holm *et al.* (2000)
	X	X	X	X	Clay	Floerl (2002)
		X			PVC	Johnston *et al.* (2002)
				✓	Wood	Mayer-Pinto & Junqueira (2003)
	X	X	X	X	Aluminium	da Fonsêca-Genevois *et al.* (2006)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
		✓			Wood	Satheesh & Wesley (2008a, b)
		X			Metal (+ epoxy primer)	Rath *et al.* (2010)
				X	Perspex	Swami & Udhayakumar (2010)
Hydroids				X	Wood	Lee & Trott (1973)
	✓	✓	✓	✓	Glass	Low *et al.* (1991)
				✓	Concrete	Rajagopal *et al.* (1997)
				✓	Fibreglass (+ anticorrosive paint)	Holm *et al.* (2000)
	X	X	X	X	Clay	Floerl (2002)
		✓			PVC	Johnston *et al.* (2002)
				✓	Wood	Mayer-Pinto & Junqueira (2003)
	X	X	✓	✓	Aluminium	da Fonsêca-Genevois *et al.* (2006)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
		✓			Wood	Satheesh & Wesley (2008a, b)
		X			Metal (+ epoxy primer)	Rath *et al.* (2010)
				✓	Perspex	Swami & Udhayakumar (2010)
Anenomes				X	Wood	Lee & Trott (1973)
	X	X	X	X	Glass	Low *et al.* (1991)
				✓	Concrete	Rajagopal *et al.* (1997)
				X	Fibreglass (+ anticorrosive paint)	Holm *et al.* (2000)
	X	X	X	X	Clay	Floerl (2002)
		X			PVC	Johnston *et al.* (2002)
				X	Wood	Mayer-Pinto & Junqueira (2003)
	X	X	X	X	Aluminium	da Fonsêca-Genevois *et al.* (2006)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
		X			Wood	Satheesh & Wesley (2008a, b)
		X			Metal (+ epoxy primer)	Rath *et al.* (2010)
				X	Perspex	Swami & Udhayakumar (2010)
Scyphozoans				X	Wood	Lee & Trott (1973)
	X	X	X	X	Glass	Low *et al.* (1991)
				X	Concrete	Rajagopal *et al.*

Taxon	Week 1	Week 2	Week 3	Week 4	Substrate	Reference
						(1997)
				X	Fibreglass (+ anticorrosive paint)	Holm *et al.* (2000)
	X	X	X	X	Clay	Floerl (2002)
		X			PVC	Johnston *et al.* (2002)
				X	Wood	Mayer-Pinto & Junqueira (2003)
	X	X	X	X	Aluminium	da Fonsêca-Genevois *et al.* (2006)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
		X			Wood	Satheesh & Wesley (2008a, b)
		X			Metal (+ epoxy primer)	Rath *et al.* (2010)
				X	Perspex	Swami & Udhayakumar (2010)
Bryozoans - encrusting				X	Wood	Lee & Trott (1973)
	X	X	X	X	Glass	Low *et al.* (1991)
				✓	Concrete	Rajagopal *et al.* (1997)
				X	Fibreglass (+ anticorrosive paint)	Holm *et al.* (2000)
	X	✓	✓	✓	Clay	Floerl (2002)
		✓			PVC	Johnston *et al.* (2002)
				X	Wood	Mayer-Pinto & Junqueira (2003)
	X	X	X	X	Aluminium	da Fonsêca-Genevois *et al.* (2006)
				✓	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
		X			Wood	Satheesh & Wesley (2008a, b)
		X			Metal (+ epoxy primer)	Rath *et al.* (2010)
				✓	Perspex	Swami & Udhayakumar (2010)
Bryozoans - arborescent				✓	Wood	Lee & Trott (1973)
	X	X	X	X	Glass	Low *et al.* (1991)
				✓	Concrete	Rajagopal *et al.* (1997)
				X	Fibreglass (+ anticorrosive paint)	Holm *et al.* (2000)
	X	✓	✓	✓	Clay	Floerl (2002)
		X			PVC	Johnston *et al.* (2002)
				✓	Wood	Mayer-Pinto & Junqueira (2003)
	X	X	X	X	Aluminium	da Fonsêca-Genevois *et al.* (2006)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
		X			Wood	Satheesh & Wesley (2008a, b)
		X			Metal (+ epoxy primer)	Rath *et al.* (2010)
				✓	Perspex	Swami & Udhayakumar (2010)
Barnacles		✓		✓	Wood	Lee & Trott (1973)
	X	✓	✓	✓	Glass	Low *et al.* (1991)
				✓	Concrete	Rajagopal *et al.* (1997)
				X	Fibreglass (+ anticorrosive paint)	Holm *et al.* (2000)
	X	✓	✓	✓	Clay	Floerl (2002)
		✓			PVC	Johnston *et al.* (2002)
				✓	Wood	Mayer-Pinto & Junqueira (2003)
	X	✓	✓	✓	Aluminium	da Fonsêca-Genevois *et al.* (2006)

Taxon	Week 1	Week 2	Week 3	Week 4	Substrate	Reference
				✓	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
		✓			Wood	Satheesh & Wesley (2008a, b)
		✓			Metal (+ epoxy primer)	Rath *et al.* (2010)
				✓	Perspex	Swami & Udhayakumar (2010)
Nematodes				X	Wood	Lee & Trott (1973)
	X	X	X	X	Glass	Low *et al.* (1991)
				X	Concrete	Rajagopal *et al.* (1997)
				X	Fibreglass (+ anticorrosive paint)	Holm *et al.* (2000)
	X	X	X	X	Clay	Floerl (2002)
		X			PVC	Johnston *et al.* (2002)
				X	Wood	Mayer-Pinto & Junqueira (2003)
	✓	✓	✓	✓	Aluminium	da Fonsêca-Genevois *et al.* (2006)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
		X			Wood	Satheesh & Wesley (2008a, b)
		X			Metal (+ epoxy primer)	Rath *et al.* (2010)
				X	Perspex	Swami & Udhayakumar (2010)
Calcareous tube-forming polychaetes				✓	Wood	Lee & Trott (1973)
	X	✓	✓	✓	Glass	Low *et al.* (1991)
				✓	Fibreglass (+ anticorrosive paint)	Holm *et al.* (2000)
				?	Concrete	Rajagopal *et al.* (1997)
	X	✓	✓	✓	Clay	Floerl (2002)
		✓			PVC	Johnston *et al.* (2002)
				X	Wood	Mayer-Pinto & Junqueira (2003)
	?	?	?	?	Aluminium	da Fonsêca-Genevois *et al.* (2006)
				✓	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
		X			Wood	Satheesh & Wesley (2008a, b)
		?			Metal (+ epoxy primer)	Rath *et al.* (2010)
				✓	Perspex	Swami & Udhayakumar (2010)
Sedimentary tube-forming polychaetes				X	Wood	Lee & Trott (1973)
	X	X	X	X	Glass	Low *et al.* (1991)
				?	Concrete	Rajagopal *et al.* (1997)
				X	Fibreglass (+ anticorrosive paint)	Holm *et al.* (2000)
	X	X	X	X	Clay	Floerl (2002)
		X			PVC	Johnston *et al.* (2002)
				✓	Wood	Mayer-Pinto & Junqueira (2003)
	?	?	?	?	Aluminium	da Fonsêca-Genevois *et al.* (2006)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
		✓			Wood	Satheesh & Wesley (2008a, b)
		?			Metal (+ epoxy primer)	Rath *et al.* (2010)
				✓	Perspex	Swami & Udhayakumar (2010)
Errant polychaetes				✓	Wood	Lee & Trott (1973)

Taxon	Week 1	Week 2	Week 3	Week 4	Substrate	Reference
	X	X	X	X	Glass	Low *et al.* (1991)
				?	Concrete	Rajagopal *et al.* (1997)
				X	Fibreglass (+ anticorrosive paint)	Holm *et al.* (2000)
	X	X	X	X	Clay	Floerl (2002)
		X			PVC	Johnston *et al.* (2002)
				X	Wood	Mayer-Pinto & Junqueira (2003)
	X	✓	✓	✓	Aluminium	da Fonsêca-Genevois *et al.* (2006)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
		✓			Wood	Satheesh & Wesley (2008a, b)
		?			Metal (+ epoxy primer)	Rath *et al.* (2010)
				X	Perspex	Swami & Udhayakumar (2010)
Isopods				X	Wood	Lee & Trott (1973)
	X	X	X	X	Glass	Low *et al.* (1991)
				X	Concrete	Rajagopal *et al.* (1997)
				X	Fibreglass (+ anticorrosive paint)	Holm *et al.* (2000)
	X	X	X	X	Clay	Floerl (2002)
		X			PVC	Johnston *et al.* (2002)
				X	Wood	Mayer-Pinto & Junqueira (2003)
	X	X	X	X	Aluminium	da Fonsêca-Genevois *et al.* (2006)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
		✓			Wood	Satheesh & Wesley (2008a, b)
		X			Metal (+ epoxy primer)	Rath *et al.* (2010)
				X	Perspex	Swami & Udhayakumar (2010)
Amphipods				✓	Wood	Lee & Trott (1973)
	X	X	X	X	Glass	Low *et al.* (1991)
					Concrete	Rajagopal *et al.* (1997)
				X	Fibreglass (+ anticorrosive paint)	Holm *et al.* (2000)
	X	✓	✓	✓	Clay	Floerl (2002)
		✓			PVC	Johnston *et al.* (2002)
				✓	Wood	Mayer-Pinto & Junqueira (2003)
	X	✓	✓	✓	Aluminium	da Fonsêca-Genevois *et al.* (2006)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
		✓			Wood	Satheesh & Wesley (2008a, b)
		X			Metal (+ epoxy primer)	Rath *et al.* (2010)
				X	Perspex	Swami & Udhayakumar (2010)
Crabs				X	Wood	Lee & Trott (1973)
	X	X	X	X	Glass	Low *et al.* (1991)
					Concrete	Rajagopal *et al.* (1997)
				X	Fibreglass (+ anticorrosive paint)	Holm *et al.* (2000)
	X	X	X	X	Clay	Floerl (2002)
		X			PVC	Johnston *et al.* (2002)
				X	Wood	Mayer-Pinto & Junqueira (2003)
	X	X	X	X	Aluminium	da Fonsêca-Genevois *et al.* (2006)

Taxon	Week 1	Week 2	Week 3	Week 4	Substrate	Reference
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
		✓			Wood	Satheesh & Wesley (2008a, b)
		X			Metal (+ epoxy primer)	Rath *et al.* (2010)
				X	Perspex	Swami & Udhayakumar (2010)
Bivalves				X	Wood	Lee & Trott (1973)
	X	X	X	X	Glass	Low *et al.* (1991)
				✓	Concrete	Rajagopal *et al.* (1997)
				X	Fibreglass (+ anticorrosive paint)	Holm *et al.* (2000)
	X	✓	✓	✓	Clay	Floerl (2002)
		✓			PVC	Johnston *et al.* (2002)
				X	Wood	Mayer-Pinto & Junqueira (2003)
	X	X	✓	✓	Aluminium	da Fonsêca-Genevois *et al.* (2006)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
		✓			Wood	Satheesh & Wesley (2008a, b)
		✓			Metal (+ epoxy primer)	Rath *et al.* (2010)
				✓	Perspex	Swami & Udhayakumar (2010)
Gastropods				✓	Wood	Lee & Trott (1973)
	X	X	X	X	Glass	Low *et al.* (1991)
				✓	Concrete	Rajagopal *et al.* (1997)
				X	Fibreglass (+ anticorrosive paint)	Holm *et al.* (2000)
	X	X	X	X	Clay	Floerl (2002)
		X			PVC	Johnston *et al.* (2002)
				X	Wood	Mayer-Pinto & Junqueira (2003)
	?	?	?	?	Aluminium	da Fonsêca-Genevois *et al.* (2006)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
		X			Wood	Satheesh & Wesley (2008a, b)
		X			Metal (+ epoxy primer)	Rath *et al.* (2010)
				X	Perspex	Swami & Udhayakumar (2010)
Sponges				X	Wood	Lee & Trott (1973)
	X	X	X	X	Glass	Low *et al.* (1991)
				✓	Concrete	Rajagopal *et al.* (1997)
				X	Fibreglass (+ anticorrosive paint)	Holm *et al.* (2000)
	X	X	X	X	Clay	Floerl (2002)
		✓			PVC	Johnston *et al.* (2002)
				X	Wood	Mayer-Pinto & Junqueira (2003)
	X	X	X	X	Aluminium	da Fonsêca-Genevois *et al.* (2006)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
		X			Wood	Satheesh & Wesley (2008a, b)
		X			Metal (+ epoxy primer)	Rath *et al.* (2010)
				✓	Perspex	Swami & Udhayakumar (2010)
Colonial ascidians				X	Wood	Lee & Trott (1973)
	X	X	X	X	Glass	Low *et al.* (1991)

Taxon	Week 1	Week 2	Week 3	Week 4	Substrate	Reference
				✓	Concrete	Rajagopal *et al.* (1997)
				✓	Fibreglass (+ anticorrosive paint)	Holm *et al.* (2000)
	X	✓	✓	✓	Clay	Floerl (2002)
		✓			PVC	Johnston *et al.* (2002)
				✓	Wood	Mayer-Pinto & Junqueira (2003)
	X	X	X	X	Aluminium	da Fonsêca-Genevois *et al.* (2006)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
		✓			Wood	Satheesh & Wesley (2008a, b)
		X			Metal (+ epoxy primer)	Rath *et al.* (2010)
				✓	Perspex	Swami & Udhayakumar (2010)
Solitary ascidians				X	Wood	Lee & Trott (1973)
	X	X	X	X	Glass	Low *et al.* (1991)
				✓	Concrete	Rajagopal *et al.* (1997)
				X	Fibreglass (+ anticorrosive paint)	Holm *et al.* (2000)
	X	✓	✓	✓	Clay	Floerl (2002)
		✓			PVC	Johnston *et al.* (2002)
				✓	Wood	Mayer-Pinto & Junqueira (2003)
	X	X	X	X	Aluminium	da Fonsêca-Genevois *et al.* (2006)
				X	PVC (+ anticorrosive paint)	Holm *et al.* (2008)
		X			Wood	Satheesh & Wesley (2008a, b)
		X			Metal (+ epoxy primer)	Rath *et al.* (2010)
				✓	Perspex	Swami & Udhayakumar (2010)