Temperature and Salinity Tolerances of Priority Marine Pests

Developed for

PIRSA Fisheries, Marine Biosecurity

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3 EXECUTIVE OVERVIEW

In planning and undertaking surveys for marine pests in Australia as part of the National System for the Prevention and Management of Marine Pest Incursions, an understanding of temperature and salinity tolerances of the pest species on the current priority list would be useful so as to focus efforts on those species that can survive in a particular area. The purpose of the present report was thus to undertake a literature review and collate the available data on temperature and salinity maxima and minima for priority marine pests. Information on the environmental cues and periods for reproduction were included where such data would be readily obtained.

Temperature and salinity maxima and minima for a total of 50 different species were considered, with summaries including an estimate of the reliability of the data (see table below). Information on many pest species was sparse or absent. For species with no directly applicable information, data were extrapolated from known their distribution and/or inferred from other members of the same genus. Neither of these approaches are considered ideal, and data reliability in these instances is given as low (L). In addition, the scientific rigour of many sources was open to question, and this information was also given a low (L) reliability index.

Data for each taxon were summarised to cover the temperature and salinity range encompassed by different strains within a species, across different congeners, and home ranges employed as proxies where direct information was lacking (Grey Background – table below).

Tolerance information was incomplete for four species, *Charybdis japonica, Megabalanus tintinnabulum, Hydroides sanctaecrucis* and *Watersipora arcuata* (Red – table below). Data for species related to these might be employed as a proxy, although retaining this group in all surveys would be preferable.

For the purposes of marine pest surveys in ports and harbours, a precautionary approach would dictate that priority pests in the low reliability category should be considered. Further, many pests (particularly the micro- and some macroalgae; Blue – table below) can occur as different strains which, when combined, have broad environmental tolerances and should be included in all surveys. It is also recommended that all microalgae (dinoflagellates and diatoms) be retained.

Summary for each species based on the highest and lowest values for temperature and salinity tolerances across strains, congeners and distributions. Blue = species which encompass different strains, Red = species where data are lacking, and grey background indicates low reliability of information. 'H' indicates high reliability of the data, while 'L' indicates that the species is known to occur at these levels but usually has not been tested outside these values.

Group	Species	Temperature °C	Salinity psu	Reliability
Microalgae	*Alexandrium catenella*	10 – 38	15 – 45	H
	Alexandrium minutum	10 – 30	4 – 37.5	H
	Alexandrium tamarense	2.5 – 30	7 – 40	H
	Gymnodinium catenatum	12.5 – 35	Min. 20	H
	Dinophysis norvegica	3.2 – 17.8	6 – 34	L
	Pfiesteria piscicida	4 – 31	0.5 – 60	H
	Pseudo-nitzschia seriata	-1.6 – 18	5 – 48	L
Macroalgae	*Caulerpa taxifolia*	9 – 32.5	Min. 17	H
	Codium fragile ssp. tomentosoides	-2 – 34	17.5 – 40	H
	Polysiphonia brodiaei	0 – 28	5 – 35	L
	Undaria pinnatifida	0 – 27	20 – 34	H
Echinoderms	*Asterias amurensis*	0 – 25	18.7 – 41	H
Crustaceans	*Carcinus maenas*	0 – 33	1.4 – 54	H
	Charybdis japonica	12 – 24	No data	L
	Eriocheir sinensis	7 – 30	0 – 35	L
	Hemigrapsus sanguineus	0.8 – 34	0 – 48	L
	Pseudodiaptomus marinus	8.9 – 28	28.6 – 32.3	L
	Balanus eburneus	16 – 32	2 – 40	L
	Balanus reticulates	6 – 44	0.5 – 40	L
	Megabalanus rosa	15 – 28	24 – 34	L
	Megabalanus tintinnabulum	Max 45	No data	H
Molluscs	*Varicorbula gibba*	-1 – 26	26 – 39	L
	Crassostrea gigas	-1.8 – 35	3.0 – 56	H
	Petricolaria pholadiformis	2 – 30	20.0 – 35	L
	Potamocorbula amurensis	0 – 28	0 – 35	L
	Musculista senhousia	-3 – 31.1	6.6 – 39	H
	Perna perna	7.5 – 30	15.0 – 55	H
	Limnoperna fortunei	10 – 32.6	0 – 3	L
	Mytilopsis sallei	5 – 40	0 – 50	H
	Perna viridis	6 – 37.5	0 – 64	H
	Crepidula fornicata	15 – 35	18.0 – 40	L
Polychaetes	*Hydroides ezoensis*	4 – 23	32.0 – 35	L
	Hydroides elegans	13 – 30	15.0 – 42	L
	Hydroides sanctaecrucis	No data	No data	
	Polydora cornuta	11 – 27	33.0 – 37	L
	Polydora websteri	1 – 18	27.0 – 32	L
	Pseudopolydora paucibranchiata	8.5 – 21	21.5 – 35	L
	Sabella spallanzanii	4 – 29	26.0 – 38	H
Tunicates	*Ciona intestinalis*	8 – 25	11.0 – 42	L
	Styela clava	-2 – 27	10.0 – 36	L
Jellyfish	*Blackfordia virginica*	10 – 32	0 – 35	L
	Mnemiopsis leidyi	1.3 – 32	3.4 – 75	L
Bryozoans	*Bugula flabellate*	9.1 – 20.7	33.4 – 37.8	L
	Bugula neritina	9.1 – 20.7	14 – 37.8	L
	Schizoporella errata	13 – 26	38.9 – 39.3	L
	Tricellaria occidentalis	9.1 – 20.7	33.4 – 37.8	L
	Watersipora arcuata	15 – 22	No data	L
	Watersipora subtorquata	12 – 28	25 – 49	L
Fish	*Neogobius melanostomus*	-1 – 30	0 – 40.6	L
	Tridentiger bifasciatus	5 – 37	0 – 21	H

4 BACKGROUND

The National System for the Prevention and Management of Marine Pest Incursions is a collaborative effort between Federal, State and Territory governments, marine industries, conservation, and research organisations. The National System comprises three key elements, which are strategically integrated to provide a holistic, practical and effective approach to marine pest management. The key elements are:

1. Prevention (both introductions to Australia and translocations within Australian waters);
2. Emergency preparedness and response (contingencies for new incursions and containment or eradication where possible); and
3. Ongoing management and control (for established pest populations).

Management of marine pests in Australian port and harbour facilities requires a capacity for regular monitoring. Traditionally, this type of survey has proven to be prohibitively expensive owing to the large number of species collected (including natives, cryptogenics and pests) with a subsequent need for prolonged and experienced taxonomic endeavour. In addition, the traditional approach does not encompass the pragmatic requirements for pest management in that most marine exotics in Australia, while undesirable, do no lasting harm (McEnnulty *et al.* 2001; Hayes *et al.* 2005) and are not subject to management strategies. As a consequence, marine pest surveys required as part of the National System will be refined to targeted searches for presence/absence of species on the relevant priority list (Table 1) that is to be further circumscribed to those organisms that are known to tolerate the temperature and salinity regime within each survey area.

For the purposes of marine pest surveys in ports and harbours, a precautionary approach would dictate that priority pests which fall into the low reliability category should be considered. Further, many pests (notably the micro- and some macroalgae; Table 3 - Blue) may occur as different strains which, when combined, have broad environmental tolerances. While new sampling technologies such as gene probes may be targeted at particular strains of a species, current searches must be at the species level. It is thus recommended that all microalgae (dinoflagellates and diatoms) be retained.

The purpose of this study was to;

1. Undertake literature searches for temperature and salinity tolerances for the current list of priority marine pests;
2. Highlight areas where these data were lacking; and
3. Provide an indication of the reliability of the available information.

With a truncated list of organisms to consider, pest surveys of ports and harbours should prove to be quicker, cheaper, more reliable and able to be completed by staff with relatively limited taxonomic experience. A total of 50 species listed as priority species under the National System were to be considered in the first instance (Table 1). This list is based on the best available information on which pests may prove problematic, but will be subject to change as new pests arrive or the priority status of an extant pest is redefined.

Table 1 - Current priority marine pest species that may be subject to management strategies under the National System, as at May 2006.

Group	Common name	Scientific name
Microalgae	Dinoflagellate	*Alexandrium catenella*
	Dinoflagellate	*Alexandrium minutum*
	Dinoflagellate	*Alexandrium tamarense*
	Dinoflagellate	*Gymnodinium catenatum*
	Dinoflagellate	*Dinophysis norvegica*
	Dinoflagellate	*Pfiesteria piscicida*
	Diatom	*Pseudo – nitzschia seriata*
Macroalgae	Aquarium strain *Caulerpa taxifolia*	*Caulerpa taxifolia*
	Green sea fingers	*Codium fragile ssp tomentosoides*
	Red macroalgae	*Polysiphonia brodiaei*
	Japanese kelp	*Undaria pinnatifida*
Echinoderms	Northern Pacific seastar	*Asterias amurensis*
Crustaceans	European green crab	*Carcinus maenas*
	Lady crab	*Charybdis japonica*
	Chinese mitten crab	*Eriocheir sinensis*
	Japanese shore crab	*Hemigrapsus sanguineus*
	Calanoid copepod	*Pseudodiaptomus marinus*
	Ivory barnacle	*Balanus eburneus*
	Barnacle	*Balanus reticulates*
	Barnacle	*Megabalanus rosa*
	Barnacle	*Megabalanus tintinnabulum*
Molluscs	Clam	*Varicorbula gibba*
	Feral Pacific oyster	*Crassostrea gigas*
	False angelwing	*Petricolaria pholadiformis*
	Brackish-water bivalve	*Potamocorbula amurensis*
	Asian date mussel	*Musculista senhousia*
	South African brown mussel	*Perna perna*
	Golden mussel	*Limnoperna fortunei*
	Black striped mussel	*Mytilopsis sallei*
	Asian green mussel	*Perna viridis*
	Slipper limpet	*Crepidula fornicata*
Polychaetes	Serpullid polychaete	*Hydroides ezoensis*
	Serpullid polychaete	*Hydroides sanctaecrucis*
	Serpullid polychaete	*Hydroides elegans*
	Spionid polychaete	*Polydora cornuta*
	Spionid polychaete	*Polydora websteri*
	Spionid polychaete	*Pseudopolydora paucibranchiata*
	Mediterranean fanworm	*Sabella spallanzanii*
Tunicates	Sea vase	*Ciona intestinalis*
	Sea squirt	*Styela clava*
Jellyfish	Black sea jelly	*Blackfordia virginica*
	Sea walnut	*Mnemiopsis leidyi*
Bryozoans	Bryozoan	*Bugula flabellate*
	Bryozoan	*Bugula neritina*
	Bryozoan	*Schizoporella errata*
	Bryozoan	*Tricellaria occidentalis*
	Bryozoan	*Watersipora arcuata*
	Bryozoan	*Watersipora subtorquata*
Fish	Round goby	*Neogobius melanostomus*
	Shimofuri goby	*Tridentiger bifasciatus*

5 INFORMATION SOURCES

Information on temperature and salinity tolerances of priority pest species has been collated through searches of available scientific and grey literature. While this investigation has been broad, there are a few key sources which have already summarised much of the available data, including:

- National Introduced Marine Pest Information System (NIMPIS) http://www.marine.csiro.au/crimp/nimpis/
- The 'Marine Life Information Network for Britain & Ireland' (MarLIN) http://www.marlin.ac.uk/index.php
- 'Invasive Species Specialist Group' (ISSG) Global Invasive Species Database http://www.issg.org/#ISSG
- Guide to the exotic species of San Francisco Bay – information on pest species http://www.exoticsguide.org/
- Gulf States Marine Fisheries Commission (GSMFC) http://www.gsmfc.org/

For each species on the target list, the maximum and minimum temperature and salinity ranges that each species can tolerate were provided. Where data were lacking, the temperature and salinity ranges of the pest's home range, or other invasion areas, were used as a proxy, in which case reliability of the information was accepted as "low". Otherwise, where little information could be found on a specific species, information on congeners was provided, again with reliability fixed at "low". In addition, some species occur in different strains, the environmental tolerances of which are often markedly different. Data for as many different strains as could be found were collected. Unless otherwise stated, data on larval stages of species was not found.

Other information on physical limitations of each taxon was noted, in particular spawning triggers and periods. In some instances no information was available on either the species, its relatives, or the home range. The reliability of each parameter for each species was estimated as either high or low based on the source (i.e. refereed scientific journals versus grey literature) and the type of information (i.e. laboratory trials versus data extrapolated from congeners or the pests home range).

6 SPECIES SUMMARIES

The information described below is summarised in Tables 2 and 3.

Some care must be taken in the interpretation of the data, as many of the critical levels have been identified as a component of treatment options for the particular pest and thus involve temperature and/or salinity levels that may be well above those that are likely to occur naturally. As a consequence, for many species the levels identified are actually exposures rather than a fixed critical point. For example, cysts of the dinoflagellate *Gymnodinium catenella* may be killed after exposure to 35 °C for 30 minutes (Hallegraeff *et al.* 1997), but need only 30-90 seconds at 40 – 45 °C (Bolch and Hallegraeff 1993). In instances such as these, the lower temperature was selected as being indicative of tolerance, although it is inherently conservative.

6.1 Microalgae

Microalgal pests include toxic dinoflagellates (*Alexandrium*, *Gymnodinium, Dinophysis* and *Pfiesteria*) and diatoms (*Pseudo-nitzschia*). These algae offer a particular challenge to marine pest survey design, as they occur in varying numbers of strains within each species, the tolerances of which may vary substantially. In most instances the range of temperature and salinity tolerances presented across the spectrum for a particular species readily encompasses most if not all the environments subject to investigation. Therefore, unless there are specific reasons not to include a particular microalgal group, it is recommended that they be retained in all marine pest surveys.

6.1.1 Alexandrium catenella

The Hong Kong strain of *Alexandrium catenella* can survive in temperatures between 10 and 30 °C (while the optimal range for growth is between 20 and 25 °C) and salinities between 15 and 45 psu with the optimal being between 30 and 35 psu (Siu *et al.* 1997). Blooms can occur at 13 °C (Rensel 1993), while survival at 30 °C is marginal (Siu *et al.* 1997). Cysts of *A. catenella* in Australia (ACSH01 and ACC501 strains from Sydney Harbour and Cowen Creek respectively) were killed after 4.5 hours at 38 °C (Hallegraeff *et al.* 1997).

6.1.2 Alexandrium minutum

Data are presented on 4 strains of *Alexandrium minutum*. Strain AM89BM from France demonstrated slow growth at 10 psu with cells eventually dying at salinities of 4, 6 and 8 psu, with growth occurring at up to 37.5 psu (Grzebyk *et al.* 2003). No temperature data are available for this strain. The strain from the Port River in South Australia is tolerant of salinities between 21 and 35 psu and while growth was tested between 12 and 25 °C the optimal temperature was 16 °C (Cannon 1993). However, this strain has not been tested outside these limits. The strain AmKB06 from Malaysia grew in salinities between 5 and 30 psu but died at 2 psu, with optimum growth at 25 psu (Lim and Ogata 2005). Again, temperature was not considered, although this strain must tolerate warmer tropical waters.

Information presented in Su *et al.* (1993) is actually for *A. minutum*, as it was wrongly identified as *A. tamarense* (Hallegraeff *et al.* 1997; Yoshida *et al.* 2000; Hewitt *et al.* 2002). This strain is tolerant of temperatures between 10 and 30 °C (Hwang and Lu 2000) but is killed after 7 days at 35.5 °C (Su *et al.* 1993) with the optimal temperature being 25 °C (Hwang and Lu 2000). Cells tolerated salinities between 7.5 and 37.5 psu, although no growth was recorded at the higher limit (Hwang and Lu 2000). Cells did not survive at 1.6 or 45 psu, and the optimal range was between 10 and 35 psu (Su *et al.* 1993).

6.1.3 Alexandrium tamarense

Prakash (1967) reported that the strain of *Alexandrium tamarense* from Canada tolerates salinities between 7 and 40 psu with the optimum at 19 – 20 psu, while temperature tolerance was between 5 and 25 °C with the optimum between 15 and 19 °C. *A. tamarense* from Massachusetts did not grow at 2.5 or 5 °C, but no death occurred at these temperatures (Anderson *et al.* 1984). No cysts were produced below 12 °C (Anderson *et al.* 1984). No salinity data for this strain have been found. The strain Pr18b from Canada exhibited inhibited growth at 10 °C with no change between 20 and 30 °C (Parkhill and Cembella 1999). For the same strain, growth was inhibited at 10 psu and showed no significant difference between 20 and 30 psu (Parkhill and Cembella 1999). The strain ATHS-92 from Japan exhibited optimal growth at 25 psu, however, growth was almost constant in the range of 13 to 38 psu (Hamasaki *et al.* 2001). The same strain displayed no growth at 12 and 22 °C and maximum growth was at 17 °C (Hamasaki *et al.* 2001). However, these data are somewhat confounded by differences in the light regimes. Strain AtPA01 from Malaysia had low growth rates at 10 and 15 psu but could survive up to 30 psu (Lim and Ogata 2005). No temperature data for this strain were found.

Reproduction for all three *Alexandrium* species is primarily asexual but they can also reproduce sexually, usually when conditions are unfavourable (i.e. nutrient depletion, high biological oxygen demand, self-shading) (Bolch *et al.* 1991; Hewitt *et al.* 2002). Reproduction cues and periods are different for each species; *A. catenella* requires elevated nutrients and temperature as well as a stable water column (Hewitt *et al.* 2002); *A. minutum* blooms in spring and autumn in South Australia and reproduction cues are unknown (Cannon 1990; 1996). Reproduction cues for *A. tamarense* include spring tides combined with increasing temperature such that it blooms in March and May in Japan (Balch 1981).

6.1.4 Gymnodinium catenatum

Gymnodinium catenatum from the Derwent and Huon Estuaries in Tasmania had optimal growth ranges of 14.5 – 20 °C and 23 – 30 psu, but stopped growing at less than 12.5 °C and 20 psu or above 25 °C (Blackburn *et al.* 1989). The upper salinity limit has not been identified. Cysts of *G. catenatum* from three Tasmanian strains (GCDE08, GCDE02 and GCHU11) were killed after 30 minutes exposure to 35 °C (Hallegraeff *et al.* 1997), although it is unlikely that this temperature is achieved in the natural state.

Gymnodinium catenatum can reproduce both sexually and asexually. A deficiency in nutrients is thought to trigger the switch from asexual to sexual reproduction (Hallegraeff *et al.* 1997). Blooms of this species are triggered when the water temperature is above 14 °C, with increased rainfall and the associated reduction in salinity, and a calm water column is crucial for blooms to develop (Hallegraeff *et al.* 1995). Data for all three *Alexandrium* species and *Gymnodinium catenatum* is given as high as it is from laboratory experiments

6.1.5 Dinophysis norvegica

The dinoflagellate *Dinophysis norvegica* occurs in the Baltic Sea in temperatures between 3.2 and 17.1 °C (Salomon *et al.* 2003), and in the North Sea in temperatures between 7 and 17.8 °C (Klöpper *et al.* 2003). Salinity tolerances reported for this species are also from known ranges, between 6 and 34 psu (Klöpper *et al.* 2003; Salomon *et al.* 2003). Reliability of this information is given as low as ranges are from known distributions only.

6.1.6 Pfiesteria piscicida

Sullivan and Anderson (2001) reported on the salinity tolerance of seven different strains of *Pfiesteria piscicida*; tolerances range from 0.5 to 60 psu. Strains 1830 and 1831 have ranges of 1 – 45 psu and 1 – 50 psu respectively, while the strain 1843 had a range of 0.5 – 55 psu. However, 55 psu treated cells were viable after being returned to 12 psu. The lower investigation limit of 0.5 psu for strains 1901, 1902 and 1921 did not kill all cells, as swimming cells were visible after being put back into 12 psu. Strains 1901, 1902 and 1921 had upper limits of 45, 55 and 60 psu respectively. The largest range is between 0.5 – 60 psu for the strain CCMP1928 (Sullivan and Anderson 2001). No data on temperature ranges could be found for these strains. Data for the salinity tolerances is given as high as it is from laboratory experiments. However, Burkholder *et al.* (1992) reported survival ranges for *P. piscicida* from the USA of 4 – 28 °C and 0 – 35 psu, the reliability of this data is reported as low as it is from known distributions rather than based on experimental evidence. However, for the same species and place, Burkholder (1995) reported survival limits between 6 and 31 °C, this data is also given low reliability.

P. piscicida is a toxic diatom that can reproduce both asexually, via temporary cysts, and sexually (Steidinger *et al.* 1996). Reproduction is stimulated by an unknown chemosensory cue in fish secreta and excreta (Steidinger *et al.* 1996).

6.1.7 Pseudo-nitzschia seriata

Growth of *Pseudo - nitzschia seriata* has been recorded between –1.6 and 12 °C, with survival (but no growth) occurring at 15 °C (Smith *et al.* 1994; Fehling *et al.* 2004). However, this species is known to occur in St Lawrence estuary in Canada at temperatures between 2 and 18 °C (Fehling *et al.* 2004). Reliability of the data for the Canadian strain is given as low as the information is from known distributions only.

P. seriata reproduces during the summer months, with increased water temperatures (Fehling *et al.* 2005). As no data for the salinity tolerance of *P. seriata* could be found, salinity ranges for seven other species of *Pseudo-nitzschia* are presented. Although *P. delicatissima*, *P. pseudodelicatissima* and *P. multiseries* (MU7 from USA) can tolerate salinity up to 45 psu, *P. delicatissima* can tolerate salinity as low as 5 psu, *P. multiseries* as low as 7 psu and *P. pseudodelicatissima* can only tolerate salinity as low as 15 psu (Thessen *et al.* 2005). Thessen *et al.* (2005) also reported that *P. brasiliana* and *P. subfraudulenta* can survive in salinities between 4 and 35 psu. *P. multiseries* (Canada) and *P. pungens* can survive in salinities between 15 to 48 and 9 to 30 psu respectively (Jackson *et al.* 1992). These ranges would suggest that *P. seriata* can tolerate a broad range of salinities.

6.2 Macroalgae

As with the dinoflagellates and diatoms, macroalgae may also occur in a variety of strains with varying environmental tolerances. Reproductive cues are poorly understood, although many pest macroalgae are readily spread via fragmentation.

6.2.1 Caulerpa taxifolia

The invasive form of the marine alga *Caulerpa taxifolia* is known to occur in a number of different strains, the precise relationships of which are difficult to determine. The Mediterranean strain survived at 6 °C for seven days, but did not survive after 2 months at 9 °C, with the upper lethal temperature between 31.5 and 32.5 °C (Komatsu *et al.* 1997; Pierre and Maricela 1999). Samples from Moreton Bay demonstrated an absolute lower limit of 9 °C with no recovery after being put back into seawater at 22 °C (Chisholm *et al.* 2000). Chisholm *et al.* (2000) did not consider temperatures upwards of 22 °C for the Moreton Bay. There are no salinity data for either the Moreton Bay or the Mediterranean strains.

Cheshire *et al.* (2002) reported that *C. taxifolia* from West Lakes was killed at salinities outside of 17 psu and 65 psu, but it has not been tested between 35 and 65 psu. Although some data is missing the reliability of the data is given as high as the ranges presented are from laboratory experiments. While *C. taxifolia* can reproduce either sexually or asexually via fragmentation, the invasive strains apparently only reproduce via fragmentation (Zuljevic and Antolic 2000).

6.2.2 Codium fragile ssp tomentosoides

The green macroalga *Codium fragile ssp tomentosoides* encounters temperatures in the NW Atlantic of –2 to 27.5 °C, with the lethal high temperature being reported as 34 °C (Trowbridge 1998). Hanisak (1979) reported that no growth occurred at temperatures below 6 °C and the optimal temperature was 24 °C for samples collected from Rhode Island. Moeller (1969) stated salinity tolerances in the range of 17.5 to 40 psu.

Codium fragile ssp tomentosoides reproduces during spring and summer once the water temperature is above 15 °C (Hewitt *et al.* 2002). Even though it can survive in temperatures between –2 and 34 °C, maximum reproduction occurs when the water is 24 °C (Hanisak 1979; Trowbridge 1998). This species can survive long periods of desiccation (Schaffelke and Dean 2005) and is capable of both sexual and asexual reproduction, the latter occurring particularly in the cooler months (Hewitt *et al.* 2002). Reliability is given as high as the temperature values presented are from laboratory experiments.

6.2.3 Polysiphonia brodiaei

Temperature tolerance values for the red macroalga, *Polysiphonia brodiaei*, are based on the environment where it is known to occur (Sweden and Port Phillip Bay). In Sweden, it is found at temperatures from 0 – 18 °C and salinities between 15 and 35 psu (Johansson *et al.* 1998). In Port Phillip Bay, Victoria, the temperature ranges from 10 – 24 °C (Jenkins 1986). As temperature and salinity values provided are only for the known range and have not been tested, reliability of the data is given as low. However, the upper limit for the congener *P. setacea* is 28 °C and at the lower limit plants were able to survive at 5 °C for 4 weeks (Rindi *et al.* 1999). Yarish *et al.* (1979) reported that *P. subtilissima* can survive in 5 psu but died after exposure to 0 psu for 3.5 days; the maximum salinity tested was 35 psu, at which all plants survived. Reliability of the data for *P. setacea* and *P. subtilissima* is given as high as they are absolute values.

Like most red macroalgae, *P. brodiaei* has a complicated life cycle, the environmental cues for reproduction are unknown.

6.2.4 Undaria pinnatifida

The Japanese kelp, *Undaria pinnatifida*, reproduces in summer, with temperature, light and depth being important developmental cues (Hewitt *et al.* 2002). It has an annual heteromorphic life cycle alternating between diploid macroscopic sporophyte and the haploid microscopic gametophyte (Hewitt *et al.* 2002).

Morita *et al.* (2003a) reported bleaching and withering of male and female gametophytes of *U. pinnatifida* at 30 °C, which were cultured from plants growing close to their southern distribution limits in Japan. Morita *et al.* (2003a) reported the upper critical temperature for growth of male and female gametophytes to be 29 °C, while the upper critical temperature for the maturation of female gametophytes was reported to be 23 °C (Morita *et al.* 2003a). *U. pinnatifida* gametophytes enter an encysted resting stage at 24 – 30 °C, but re-commence growth if temperatures fall below 24 °C (Saito 1975). In northern France, the lowest temperature for recruitment is 5 °C with the lower and upper lethal temperatures reported to be < 0 °C and > 25 °C, respectively (Castric-Fey *et al.* 1999). While growth is possible at 3 °C (Sanderson 1990) both the gametophyte and sporophyte are known to occur between 0 and 27 °C in Japan (Hay 1990). The critical upper temperatures for growth reported from Japan are 25 °C (Akiyama 1965) and 27 °C (Morita *et al.* 2003b).

The lowest salinity at which *U. pinnatifida* establishes and grows is 20 – 25 psu in Venice (Curiel *et al.* 2002). Optimal salinity for growth is 27 – 33 psu (Bardach *et al.* 1972). Growth is possible at 27 psu (Saito 1975), and has been recorded at 22 and 23 psu in New Zealand (Wallentinus 1999) and between 29 and 34 psu in Japan (Yoshikawa *et al.* 2001). The tolerances outlined above suggest that in Tasmania and Port Phillip Bay, where the annual range of sea temperatures varies from 10 – 20 °C and from 11 – 21 °C respectively, development of gametophytes and sporophytes is likely to occur all year round. The salinity tolerance of *U. pinnatifida* indicates its potential to establish in estuarine and marine habitats along the southern Australian coast. Reliability of the data is given as high as both the sporophyte and gametophyte have to be present for this species to reproduce.

6.3 Echinoderms

6.3.1 Asterias amurensis

Adults of the Northern Pacific seastar, *Asterias amurensis*, survive in water temperatures ranging from 0 to 25 °C (Ino *et al.* 1955), although they lose weight below 4 and above 20 °C (Hawkes and Day 1993). Juveniles died when exposed to 29 °C for 2 days and 1.1 °C for 4 days (Hawkes and Day 1993). Sexual reproduction occurs within the temperature range of 5 to 23 °C and at salinities of 29.5 to 34.8 psu (Hewitt *et al.* 2002). The optimal salinity for the development of larvae is 32 psu. However, larvae can survive short (10 minute) exposure to salinities < 17.5 psu, but die at salinities < 8.75 psu (Sutton and Bruce 1996). *A. amurensis* occurs at salinities as low as 18.7 psu in Hendersons Lagoon, Tasmania (Hewitt *et al.* 2002) and as high as 41 psu (Thomson and Watson 1994). Reliability of this data is high as the data shown are from laboratory experiments.

A. amurensis is capable of both sexual (in winter) and asexual reproduction by fragmentation, provided part of the central disc is attached to the amputated arm (Hewitt *et al.* 2002). Eggs and sperm are released into the water column with females capable of producing between 10 and 25 million eggs per year, and larvae are able to remain in the water column for up to 120 days (Hewitt *et al.* 2002).

6.4 Crustaceans

6.4.1 Carcinus maenas

The European green crab, *Carcinus maenas*, reproduces in summer for a period of four months; reproduction begins when the females begin to moult. The European green crab can survive in a wide range of temperatures and salinities (Cohen *et al.* 1995; Ruiz *et al.* 1998; Cameron and Metaxas 2005). Adult *C. maenas* occur at depths between 0 and 60 m and are reported to survive in temperatures ranging between 1 and 26 °C (Cohen *et al.* 1995), 3 – 26 °C (Ruiz *et al.* 1998) and 0 – 33 °C (Washington Department of Fish and Wildlife 2001), but die if subjected to 0 °C for sustained periods (Cohen *et al.* 1995). Feeding is reduced at 6 – 7 °C and ceases at <6 °C. *C. maenas* is a euryhaline organism with optimal salinity ranges of 22 – 41 psu in the laboratory (Cohen *et al.* 1995), and 10 – 33 psu (Ruiz *et al.* 1998). *C. maenas* survive minimum and maximum salinities of 4 psu and 54 psu, but is known to tolerate 1.4 psu during flooding of intertidal zones (Cohen *et al.* 1995; Washington Department of Fish and Wildlife 2001), for short periods of time. Reliability of this information is given as high as upper and lower lethal temperatures and salinities have been found.

6.4.2 Charybdis japonica

The lady crab, *Charybdis japonica*, reproduces in summer and autumn in Asia (Oishi and Saigusa 1997; Jeffs and James 2001; Vazquez Archdale *et al.* 2003). Very little information on this species could be found, the temperature range (12 – 24 °C) is based on the known distribution in New Zealand only and therefore reliability is given as low. No data on salinity tolerances have been found.

6.4.3 Eriocheir sinensis

The Chinese mitten crab, *Eriocheir sinensis*, is catadromous (living in freshwater but migrates to the sea to breed) with mating occurring under hard-shell conditions usually during late autumn through winter (Veldhuizen and Stanish 1999), and spawning occurring where the average salinity is 20 psu (Anger 1991). Successful development of larvae requires temperatures above 9 °C and access to a range of salinities (Veldhuizen and Stanish 1999). For both juveniles and adults, growth stops at temperatures below 7 °C and above 30 °C, with optimal growth occurring between 20 and 30 °C (Hymanson *et al.* 1999). Adult crabs can survive in water temperatures of 0 °C for up to 7 days, with normal activity returning if placed back into warmer waters (Veldhuizen and Stanish 1999). *E. sinensis* can survive in salinities between 0 and 35 psu (Rudnick *et al.* 2003). However, salinity tolerances above 35 psu have not been tested. The reliability of the data is given as high/low as temperature has been well investigated but the upper salinity values have not. Juvenile and adult crabs can survive out of the water for long periods.

6.4.4 Hemigrapsus sanguineus

The Japanese shore crab, *Hemigrapsus sanguineus*, is found at temperatures between 0.8 and 27 °C and in salinities between 30 and 33 psu (McDermott 1998); reliability of this information is given as low as these ranges are based on known distributions. Epifanio *et al.* (1998) reported that no larvae were able to survive to the adult stage at salinities lower than 10 psu and larvae did not develop at temperatures below 20 °C. As little information could be found, data are presented for three congeners, *H. nudus*, *H. edwardsii* and *H. crenulatus*. *H. nudus* can tolerate water temperatures between 3.5 and 34 °C (McGraw 2003) and salinities between 2 and 32 psu. McGraw (2001) reported 100% mortality after 24 hours exposure to 0 psu, while 32 psu was the highest salinity tested for *H. nudus*. Both *H. edwardsii* and *H. crenulatus* can survive in similar temperatures between 7 – 24 °C and 6 – 23 °C respectively, although *H. edwardsii* can survive in salinities between 24 and 48 psu, while *H. crenulatus* can survive in the wider range of 12 – 42 psu (Hicks 1973). Reliability of this data is given as high as the information presented is from laboratory experiments.

6.4.5 Pseudodiaptomus marinus

The calanoid copepod, *Pseudodiaptomus marinus*, is an egg carrying planktonic copepod. From its known distribution in Japan, it can survive in temperatures between 8.9 and 28.2 °C and salinities from 28.6 to 32.3 psu (Liang and Uye 1997). Reliability of this data is given as low as it is from known distributions only.

6.4.6 Balanus eburneus

The ivory barnacle, *Balanus eburneus*, occurs between temperatures of 16 and 32 °C, while salinity survival limits are between 2 and 40 psu (Bacon 1971; Dineen and Hines 1994b; Brown and Swearingen 1998). Low reliability is given for this data as it is from known distributions.

6.4.7 Balanus reticulates

For the barnacle *B. reticulatus*, both the temperature (6 – 29 °C) and salinity (20 – 40 psu) tolerances reported by Thiyagarajan *et al.* (2002) have not been fully tested, and therefore reliability is given as low.

Thus, data for three non-pest *Balanus* species have been included. The maximum upper lethal temperature for *B. balanoids* is 44 °C (Foster 1969) but no lower lethal temperature or salinity ranges were available for this species. However, reliability is given as high as an upper lethal temperature has been identified. *B. amphitrite* survived between temperatures of 15 and 30 °C, while after three days immersion at 5 psu all individuals were dead (Qiu and Qian 1999).

Reliability of this data is given as low, as the temperature range given is not the absolute maximum and no maximum salinity tolerance was found. The temperature range for *B. subalbidus* of 5 to 22 °C was from known distribution of the species and not experimental data (Dineen and Hines 1994a), hence reliability is therefore given as low. The lower salinity value of 0.5 psu in Table 3 is also from the known distribution, while the upper limit of 35 psu was from experimental data (Dineen and Hines 1994a).

6.4.8 Megabalanus rosa

Both the temperature (15 – 28 °C) and salinity (24 – 34 psu) ranges for *Megabalanus rosa* are from known distributions in Japan (Anil *et al.* 1990). Reliability of the data for *M. rosa* is given as low as it is from known distributions.

6.4.9 Megabalanus tintinnabulum

The only data found on *M. tintinnabulum* is that it took 810 minutes for 100% mortality at 36 °C but only 2 minutes at 45 °C (Samuel Jesudoss *et al.* 1997). However, reliability is given as high as an absolute upper lethal temperature has been identified.

Both *M. rosa* and *M. tintinnabulum* are hermaphrodites, with the cue for reproduction being an increase in water temperature (Hewitt *et al.* 2002).

6.5 Molluscs

6.5.1 Varicorbula gibba

The clam, *Varicorbula gibba*, has separate sexes and is a broadcast spawner, with reproduction and settlement taking place during summer and autumn (Hewitt *et al.* 2002). In Limfjord (Denmark), it occurs at temperatures between –1 and 16 °C (Jensen 1988, 1990). Growth has been recorded between 11.3 and 24.3 °C in Elefsis Bay, Greece (Theodorou 1994) and 8 – 26 °C in Port Phillip Bay (Talman 2000; Talman and Keough 2001). *V. gibba* has been recorded at the following salinities; 26 – 39 psu in Port Phillip Bay (Talman 2000; Talman and Keough 2001); 28 – 34 psu in Limfjord, Denmark, (Jensen 1990); 27 – 32 psu in Nissum Bredning, Denmark (Jensen 1988); and 38.2 – 38.6 psu in Elefsis Bay, Greece (Theodorou 1994). Reliability of this information is given as low as all data presented are from known ranges worldwide.

6.5.2 Crassostrea gigas

The Pacific oyster, *Crassostrea gigas*, begins life as a male and after a year begins to function as a female. Spawning begins when water temperature increases and may coincide with phytoplankton blooms, usually during summer (Hewitt *et al.* 2002). This species has a wide temperature tolerance from –1.8 to 35 °C. Rajagopal *et al.* (2005) reported that specimens were dead after one-hour exposure to 43 °C. In terms of salinity, Chu *et al.* (1996) reported 50% mortality at 3 psu, and *C. gigas* is known to survive at 56 psu for up to four days (Hopkins 1936). Reliability of the information presented is given as high as the data is from laboratory experiments.

6.5.3 Petricolaria pholadiformis

Very little information could be found on the false angelwing, *Petricolaria pholadiformis*; the values provided (temperature range of 2 – 30 °C; salinity range of 20 – 35 psu) are those for Newport Bay where this species is known to occur (Maryland Department of Natural Resources 2006). As the ranges presented are from known distributions only, data reliability is given as low.

6.5.4 Potamocorbula amurensis

The brackish-water bivalve, *Potamocorbula amurensis*, occurs as separate sexes with reproduction cues including physical stress, heat shock and rough handling (Nicolini and Penry 2000). It reproduces between May and June as well as between September and October in Korea (Hewitt *et al.* 2002).

P. amurensis can survive in water temperatures between 0 and 28 °C in Asia (Carlton *et al.* 1990). However, Koh and Shin (1988) reported water temperature within the sediment of between –3.5 and 37.8 °C in areas where this species is known to occur. *P. amurensis* can survive prolonged exposure to varying salinities between 0 and 35 psu (Nicolini and Penry 2000). As data is only from known distributions, reliability is recorded as low.

6.5.5 Musculista senhousia

The Asian date mussel, *Musculista senhousia*, has separate sexes, with increased water temperatures believed to induce spawning (Hewitt *et al.* 2002). Reported reproduction periods in the northern hemisphere are between September and November (Sgro *et al.* 2002). It is found in temperatures ranging from 12 – 26 °C in Mission Bay (USA) (Crooks 1996). In the laboratory, mortality occurs within 3 days at temperatures between –3 and –5 °C (Guan *et al.* 1989) and peaks of planktonic larvae were found at a water temperature of 31.1 °C (Miyawaki and Sekiguchi 1999). Growth occurs at salinities of 6.6 – 29.9 psu in Japan (Miyawaki and Sekiguchi 1999), 13 – 22 psu in USA (Reusch and Williams 1998), and 10 – 21 psu in Russia (Kulikova 1978). Ambient salinities reported for survival are: 34 – 35.5 psu in San Diego Bay (Reusch and Williams 1998), 30.6 – 32 psu in Korea, and 11.2 – 28.8 psu in China (Guan *et al.* 1989). It is known to grow between 34 and 39 psu in the Mediterranean Sea (Mastrototaro *et al.* 2003). As data is only from known distributions of the species, reliability is recorded as low.

6.5.6 Perna perna

The South African brown mussel, *Perna perna* occurs as separate sexes and spawns through external fertilization by releasing eggs and sperm into the water column. It is thought that a drop in water temperature is the cue for reproduction (Lasiak 1986). In South Africa, various reproduction periods have been reported for this species including May to October (Berry 1978), and April to September and December to February (Lasiak 1986). The long-term upper and lower temperature limits for *P. perna* are between 7.5 and 30 °C (Hicks and McMahon 2002). The adult salinity tolerance of this species is between 19 and 44 psu (Salomao *et al.* 1980), but the veligers are reported to survive in salinities between 15 and 55 psu (Romero and Moreira 1980). The reliability of the temperature data is given as high as upper and lower limits can be identified. However, the salinity data is given as low as it is from known distributions.

6.5.7 Limnoperna fortunei

In South American rivers, the Golden mussel, *Limnoperna fortunei*, is capable of continuous reproduction throughout the year (Brugnoli *et al.* 2005), although the threshold temperature for the onset of reproduction is between 15 and 17 °C (Darrigran 2002).

L. fortunei is exclusively a freshwater mussel and is found in temperatures between 10 and 32.6 °C and salinities between 0 and 3 psu (Deaton *et al.* 1989; Darrigran 2002; Sylvester *et al.* 2005). The reliability of these data is given as low as these ranges are based on known distributions.

6.5.8 Mytilopsis sallei

A proportion of the black striped mussel, *Mytilopsis sallei*, populations become hermaphroditic as they age, with the remainder persisting as males. Eggs and sperm are spawned into the water column, where external fertilisation takes place (Hewitt *et al.* 2002). Cues for reproduction include a reduction in salinity (<20 psu) and over-crowding (Kalyanasundaram 1975). In the laboratory, this species survives temperatures between 5 and 40 °C (Rao *et al.* 1975), with death occurring within 4 hours at 45 °C (Kalyanasundaram 1975). *M. sallei* has survived in freshwater for nine months (Karande and Menon 1975), but after exposure to 50 psu, animals did not resume normal activity (Kalyanasundaram 1975). Reliability for *M. sallei* is given as high as absolute upper and lower temperature and salinity values have been identified.

6.5.9 Perna viridis

The Asian green mussel, *Perna viridis*, is a broadcast spawner with separate sexes (Hewitt *et al.* 2002), and reproduction cues include an increase in water temperature (Siddall 1980) and decrease in salinity due to heavy rains (Stephen and Shetty 1981). Segnini de Bravo *et al.* (1998) reported 100% mortality at 6 °C and 50% mortality at 37.5 °C and upper and lower lethal salinity values of 0 and 64 psu respectively. Reliability is given as high as tolerances are from laboratory experiments.

6.5.10 Crepidula fornicata

The slipper limpet, *Crepidula fornicata*, can survive in temperatures between 15 °C and 35 °C (Lucas and Costlow 1979). After exposure at 35 °C, embryos and adults died within 2 days, although the lowest temperature considered (15 °C) had little effect (Lucas and Costlow 1979). *C. fornicata* is able to survive in salinities between 18 and 40 psu (Rayment 2006). However, these are ranges within known distributions and reliability of the data is given as low.

C. fornicata is a protandrous hermaphrodite (Rayment 2006). In the northern hemisphere, females spawn between February and October, with the peak season occurring in May and June (Rayment 2006). The cue for reproduction is neap tides.

6.6 Polychaetes

Very little information was found for the serpullid polychaetes and reliability for all species where information could be obtained is low.

6.6.1 Hydroides ezoensis

Temperature (4 – 23 °C) and salinity (32 – 35 psu) data for *Hydroides ezoensis* is from a known population in Langstone Harbour (Brown and Eaton 2001), therefore reliability of the data is low.

6.6.2 Hydroides elegans

Hydroides elegans from the Aegean Sea and Hong Kong had a temperature range from 13 to 30 °C (Qiu and Qian 1998; Kocak and Kucuksezgin 2000). Mak and Huang (1982) reported 90% mortality for *H. elegans* after 45 hours at 15 psu, while the maximum salinity of 42 psu is also from the Aegean Sea (Kocak and Kucuksezgin 2000), and therefore reliability is given as low.

6.6.3 Hydroides sanctaecrucis

No data were found for the serpullid polychaete *Hydroides sanctaecrucis*.

6.6.4 Polydora cornuta

The spionid polychaete, *Polydora cornuta*, is known to survive in temperatures between 11 and 27 °C and in salinities between 33 and 37 psu (Cinar *et al.* 2005); the reliability of this information is given as low as it is only from the distribution of a known population in Turkey.

6.6.5 Polydora websteri

Polydora websteri can survive in temperatures between 1 and 18 °C and salinities between 27 and 32 psu (Evans 1969; Breves-Ramos *et al.* 2005). As the temperature data is from known populations in Newfoundland and the salinity data is from Brazil, reliability of the information is given as low.

6.6.6 Pseudopolydora paucibranchiata

Both temperature (8.5 – 21 °C) and salinity (21.5 – 35 psu) values for the polychaete *Pseudopolydora paucibranchiata* are the range of Port Phillip Bay (Coleman and Sinclair 1996); therefore reliability is low. *P. paucibranchiata*, a spionid polychaete, has two distinct sexes, with fertilisation occurring internally, which is achieved by the transfer of a spermatophore from the male to the female (Hewitt *et al.* 2002). This species reproduces between March and September in New Zealand (Read 1975).

6.6.7 Sabella spallanzanii

In laboratory trials, the Mediterranean fanworm, *Sabella spallanzanii*, survived at 4 °C for 12 hours (Clapin 1996). During a study of *S. spallanzanii* off the Italian coast, water temperature reached 29 °C (Giangrande and Petraroli 1994). *S. spallanzanii* is known to survive in salinities between 26 and 38 psu at Queenscliff, Victoria (Currie *et al.* 2000) and dies after 2 hours exposure to freshwater (Gunthrope *et al.* 2001). Reliability is given as low as only the lower salinity limit has been identified.

S. spallanzanii is a broadcast spawner with separate sexes (Hewitt *et al.* 2002). Spawning cues include falling water temperatures and shorter day lengths (Currie *et al.* 2000; Giangrande *et al.* 2000).

6.7 Tunicates

6.7.1 Ciona intestinalis

Larval development of the sea vase, *Ciona intestinalis*, occurs between temperatures of 8 and 25 °C (Bellas *et al.* 2003). In the Mediterranean, most of the adult population dies when temperatures fall below 10 °C, although in Sweden, reproduction can occur when temperatures are above 8 °C (Jackson 2005). This species can survive in salinities as low as 11 psu (Jackson 2005) and up to 42 psu (Bellas *et al.* 2003). Reliability of this data is given as low as it is from known distributions only.

6.7.2 Styela clava

The sea squirt, *Styela clava*, grows in areas where the ambient temperature goes as low as –2 °C and as high as 27 °C on the Pacific coast of America (Cohen 2005). Salinities on the Pacific coast vary between 22 and 36 psu, but adults cannot survive in salinities below 10 psu and the larvae of this species dies below 18 psu (Cohen 2005). As the data is from a known distribution of the species reliability of the data is given as low.

Both *C. intestinalis* and *S. clava* are hermaphrodites (Niermann-Kerkenberg and Hofmann 1989; Kashenko 1996), releasing eggs into the water column, either individually or in mucous strands where fertilisation takes place (Petersen and Svane 1995; Hewitt *et al.* 2002).

6.8 Jellyfish

6.8.1 Blackfordia virginica

The black sea jelly, *Blackfordia virginica*, is able to tolerate temperatures between 10 and 32 °C (Vannucci *et al.* 1970; Mills and Sommer 1995) and salinities between 0 and 35 psu (Moore 1987). As these values are from known distributions only, reliability is given as low.

6.8.2 Mnemiopsis leidyi

The comb jelly, *Mnemiopsis leidyi*, is able to survive in a wide range of temperatures between 1.3 °C (Burrell and Van Engel 1976) and 32 °C (GESAMP 1997) and salinities from 3.4 psu (Miller 1974) to 75 psu (GESAMP 1997). Reliability of this data is given as low as the ranges are only from known populations and have not been experimentally tested.

M. leidyi is a self-fertilising, simultaneous hermaphrodite capable of releasing both eggs and sperm into the water for external fertilisation to take place (Hewitt *et al.* 2002). *M. leidyi* spawns at night with cues for reproduction being high concentrations of medium size copepods and temperatures above 20 °C (Zaika and Sergeeva 1994). Although spawning in the USA occurs between spring and summer (June-October), in the Black Sea, *M. leidyi* is capable of reproducing all year round, with a peak between October-November (Hewitt *et al.* 2002).

6.9 Bryozoans

6.9.1 Bugula flabellate

The bryozoan, *Bugula flabellate*, is found in Port Phillip Bay, Victoria, which has a temperature range of 9.1 to 20.7 °C and a salinity range of 33.4 to 37.8 psu (Jenkins 1986). Data reliability is given as low as it is from known distributions only.

6.9.2 Bugula neritina

Bugula neritina is also found in Port Phillip Bay, and has the same temperature range and upper salinity tolerance (and low reliability) of *B. flabellate*. However, salinities below 18 psu are detrimental to colonies and salinity lower than 14 psu is fatal (Mawatari 1951).

Both *B. flabellate* and *B. neritina* are protogynous hermaphrodites. Once larvae are released they metamorphose and produce a bushy colony by rapid asexual budding (Dyrynda and Ryland 1982; Hewitt *et al.* 2002).

6.9.3 Schizoporella errata

Schizoporella errata is known to occur in water temperatures in the range of 13 and 26 °C and salinities between 38.9 and 39.3 psu in Greece (Brown *et al.* 2003). As these ranges are only from a known population, data reliability is given as low.

6.9.4 Tricellaria occidentalis

Tricellaria occidentalis occurs in Port Phillip Bay and similar temperature and salinity tolerances have been derived as for *Bugula flabellate*, with similarly low data reliability.

6.9.5 Watersipora arcuata

Watersipora arcuata is found in Sydney waters between the temperatures of 15 and 22 °C (Wisely 1958), therefore reliability of the data is given as low. No data for salinity tolerance could be found.

W. arcuata is capable of reproducing asexually (via fragmentation) or sexually. Being a hermaphrodite, the bryozoan is capable of self-fertilization after which larvae are released, settling within 24 hours (Hewitt *et al.* 2002). *W. arcuata* is highly phototrophic and a strong light intensity can induce spawning (Wisely 1958). It is capable of spawning all year round, but peaks between February-May when water temperatures are around 20 °C in the southern hemisphere (Hewitt *et al.* 2002).

6.9.6 Watersipora subtorquata

Watersipora subtorquata is also capable of both asexual and sexual reproduction. In California, it has been collected at temperatures between 12 and 27 °C and in Japan from 12 to 28 °C (Cohen 2005). In California, it is found at salinities between 25 – 37 psu, but has also been found at salinities up to 49 psu in the Suez Canal (Cohen 2005). As the data is from known populations data reliability is given as low.

6.10 Fish

6.10.1 Neogobius melanostomus

The round goby, *Neogobius melanostomus*, is found in temperatures between –1 and 30 °C (Ilyin 1949 in Stepanova *et al.* 2005) and salinities between 0 and 40.6 psu (Charlebois *et al.* 1997).

N. melanostomus spawns both in fresh and saline water (Stepanova *et al.* 2005). In the Black and Caspian seas of northern Europe, the round goby's spawning period begins in spring, lasting from April to September (Charlebois *et al.* 1997).

6.10.2 Tridentiger bifasciatus

The shimofuri goby, *Tridentiger bifasciatus*, is able to survive in temperatures as low as 5 °C, as it has been recorded in Suisun Marsh in San Francisco Bay (Matern and Brown 2005). The critical thermal maximum for this species is 37 °C (Matern 2001). *T. bifasciatus* is able to survive in salinities near 0 psu (Matern and Brown 2005) and up to 21 psu (Matern 2001). Reliability of this data is given as low as it is from known populations. However, the upper thermal limit has been identified.

No available data on growth, reproduction cues or periods has been found for this species.

Table 2 - Temperature and salinity tolerances of all species. 'H' indicates high reliability of the data, while 'L' indicates that the species is known to occur at these levels but usually has not been tested outside these values.

Group/Species	Strain/Congener	Temperature °C	Salinity psu	Source(s)	Reliability
Microalgae					
Alexandrium catenella	Hong Kong	10 – 30	15 – 45	Sui et al. 1997	H
	ACSH01 Sydney Harbour	Max 38	No Data	Hallegraeff et al. 1997	H
	ACC501 Cowen Creek, NSW	Max 38	No Data	Hallegraeff et al. 1997	H
Alexandrium minutum	AM89BM Morlaix B., France	No data	4 – 37.5	Grzebyk et al. 2003	H
	Port River, SA	12 – 25	21 – 35	Cannon 1993	H
	T1 Taiwan	10 – 30	7.5 – 37.5	Hwang and Lu 2000	H
	AmKB06 Getting R., Malaysia	No data	2 – 30	Lim and Ogata 2005	H
Alexandrium tamarense	Bay of Fundy, Canada	5 – 25	7 – 40	Prakash 1967	H
	Mill Pond, Massachusetts, USA	2.5 – 26	No data	Anderson et al. 1984	H
	Pr18b Lawrence Estuary, Canada	10 – 30	10 – 30	Parkhill and Cembella 1999	H
	ATHS-92 Hiroshima B., Japan	12 – 22	13 – 38	Hamasaki et al. 2001	H
	AtPA01 Aman Island, Malaysia	No data	10 – 30	Lim and Ogata 2005	H
Gymnodinium catenatum	Derwent R. and Huon R., Tasmania	12.5 – 25	Min. 20	Blackburn et al. 1989	H
	GDCE08 Derwent Estuary, Tasmania	Max 35	No data	Hallegraeff et al. 1997	H
	GDCE02 Derwent Estuary, Tasmania	Max 35	No data	Hallegraeff et al. 1997	H
	GCHU11 Huon Estuary, Tasmania	Max 35	No data	Hallegraeff et al. 1997	H
	Hiroshima B., Japan	7.5 – 30	10 – 35	Yamamoto et al. 2002	H
	GCCV-10 Gulf of California, Mexico	5 – 35	10 – 40	Band-Schmidt et al. 2004	H
	Ria de Vigo, Spain	6 – 32	No data	Bravo and Anderson 1994	H
Dinophysis norvegica		3.2 – 17.8	6 – 34	Klöpper et al. 2003 Salomon et al. 2003	L

Group/Species	Strain/Congener	Temperature °C	Salinity psu	Source(s)	Reliability
Pfiesteria piscicida	CCMP1830 Chicamacmico R., Chesapeake B., USA	No data	1 – 45	Sullivan and Anderson 2001	H
	CCMP1831 Chicamacmico R., Chesapeake B., USA	No data	1 – 50	Sullivan and Anderson 2001	H
	CCMP1834 Pokomoke R., Chesapeake B., USA	No data	0.5 – 55	Sullivan and Anderson 2001	H
	CCMP1901 Chesapeake B., USA, axenic strain	No data	0.5 – 45	Sullivan and Anderson 2001	H
	CCMP1902 Chesapeake B., USA, axenic strain	No data	0.5 – 55	Sullivan and Anderson 2001	H
	CCMP1921 Chicamacmico R., Chesapeake B., USA	No data	0.5 – 50	Sullivan and Anderson 2001	H
	CCMP1928 – Wilmington R., Georgia, USA	No data	0.5 – 60	Sullivan and Anderson 2001	H
	USA, Pamlico R. Est., North Carolina, USA	6 – 31	No data	Burkholder et al. 1995	L
	USA, Pamlico R. Est., North Carolina, USA	4 – 28	0 – 35	Burkholder et al. 1992	L
Pseudo-nitzschia seriata	Resolute, Canada	-1.6 – 18	No data	Smith et al. 1994 Fehling et al. 2004	L
	P. delicatissima LaPn-4 Louisiana, Texas Shelf, USA	No data	5 – 45	Thessen et al. 2005	H
	P. pseudodelicatissima CCMP 1823 Louisiana, Texas Shelf, USA	No data	15 – 45	Thessen et al. 2005	H
	P. multiseries MU 7 Louisiana, Texas Shelf, USA	No data	7 – 45	Thessen et al. 2005	H
	P. multiseries Pomquet Harbor, Canada	No data	15 – 48	Jackson et al. 1992	H
	P. pungens Brudness R., Canada	No data	9 – 30	Jackson et al. 1992	H
	P. brasiliana Louisiana Texas Shelf, USA	No data	4 – 35	Thessen et al. 2005	H
	P. subfraudulenta Louisiana Texas Shelf, USA	No data	4 – 35	Thessen et al. 2005	H

Macroalgae

Group/Species	Strain/Congener	Temperature °C	Salinity psu	Source(s)	Reliability
Caulerpa taxifolia	Mediterranean	9 – 32.5	No data	Komatsu et al. 1997 Pierre and Maricela 1999	H
	Moreton B., QLD	9 – 22	No data	Chisholm et al. 2000	H
	West Lakes/Port R., SA	No data	Min 17	Collings et al. 2004	H
Codium fragile ssp. tomentosoides		-2 – 34	17.5 – 40	Moeller 1969 Trowbridge 1998	H
Polysiphonia brodiaei		0 – 20.7	15 – 35	Jenkins 1986 Johansson et al. 1998	L
	P. setacea	5 – 28	No data	Rindi et al. 1999	H
	P. subtilissima	No data	5 – 35	Yarish et al. 1979	H

Group/Species	Strain/Congener	Temperature °C	Salinity psu	Source(s)	Reliability
Undaria pinnatifida		0 – 27	20 – 34	Yoshikawa et al. 2001 Curiel et al. 2002 Morita et al. 2003b	H
Echinoderms					
Asterias amurensis		0 – 25	18.7 – 41	Ino et al. 1955 Park and Kim 1985 Thomson and Watson 1994 Hewitt et al. 2002	H
Crustaceans					
Carcinus maenas		0 – 33	1.4 – 54	Cohen et al. 1995 Washington Department of Fish and Wildlife 2001	H
Charybdis japonica		12 – 24	No data	Jeffs and James 2001	L
Eriocheir sinensis		7 – 30	0 – 35	Anger 1991 Hymanson et al. 1999 Rudnick et al. 2003	H/L
Hemigrapsus sanguineus		0.8 – 27	30 – 33	Epifanio et al. 1998 McDermott 1998	L
	H. nudus	3.5 – 34	0 – >32	McGaw 2001 McGaw 2003	H
	H. edwardsii	7 – 24	24 – 48	Hicks 1973	H
	H. crenulatus	6 – 23	12 – 42	Hicks 1973	H
Pseudodiaptomus marinus		8.9 – 28.2	28.6 – 32.3	Liang and Uye 1997	L
Balanus eburneus		16 – 32	2 – 40	Bacon 1971 Dineen and Hines 1994b Brown and Swearingen 1998	L

Group/Species	Strain/Congener	Temperature °C	Salinity psu	Source(s)	Reliability
Balanus reticulates		6 – 29	20 – 40	Thiyagarajan et al. 2002	L
	B. balanoides	Max 44	No data	Foster 1969	H
	B. amphitrite	15 – 30	Min 10	Qiu and Qian 1999	L
	B. subalbidus	5 – 22	0.5 – 35	Dineen and Hines 1994a	L
Megabalanus rosa		15 – 28	24 – 34	Anil et al. 1990	L
Megabalanus tintinnabulum		Max 45.0	No data	Samuel Jesudoss 1997	H

Molluscs

Group/Species	Strain/Congener	Temperature °C	Salinity psu	Source(s)	Reliability
Varicorbula gibba		-1 – 26	26 – 39	Jensen 1988 Talman 2000	L
Crassostrea gigas		-1.8 – 35	3 – 56	Hopkins 1936 Mann et al. 1991 Chu et al. 1996 Shatkin et al. 1997	H
Petricolaria pholadiformis		2 – 30	20 – 35	Maryland Department of Natural Resources 2006	L
Potamocorbula amurensis		0 – 28	0 – 35	Carlton et al. 1990 Nicolini and Penry 2000	L
Musculista senhousia		-3 – 31.1	6.6 – 39	Guan et al. 1989 Miyawaki and Sekiguchi 1999 Mastrototaro et al. 2003	H/L
Perna perna		7.5 – 30	15 – 55	Salomao et al. 1980 Hicks and McMahon 2002	H
Limnoperna fortunei		10 – 32.6	0 – 3	Deaton et al. 1989 Darrigran 2002 Sylvester et al. 2005	L

Group/Species	Strain/Congener	Temperature °C	Salinity psu	Source(s)	Reliability
Mytilopsis sallei		5 – 40	0 – 50	Kalyanasundaram 1975 Rao et al. 1975	H
Perna viridis		6 – 37.5	0 – 64	Segnini de Bravo et al. 1998	H
Crepidula fornicata		15 – 35	18 – 40	Lucas and Costlow 1979 Rayment 2006	L
Polychaetes					
Hydroides ezoensis		4 – 23	32 – 35	Brown and Eaton 2001	L
Hydroides elegans		13 – 30	15 – 42	Mak and Huang 1982 Qiu and Qian 1998 Kocak and Kucuksezgin 2000	L
Hydroides sanctaecrucis		No data	No data		
Polydora cornuta		11 – 27	33 – 37	Cinar et al. 2005	L
Polydora websteri		1 – 18	27 – 32	Breves-Ramos et al. 2005 Evans 1969	L
Pseudopolydora paucibranchiata		8.5 – 21	21.5 – 35	Coleman and Sinclair 1996	L
Sabella spallanzanii		4 – 29	26 – 38	Clapin 1996 Currie et al. 2000 Giangrande et al. 2000	L

Group/Species	Strain/Congener	Temperature °C	Salinity psu	Source(s)	Reliability
Tunicates					
Ciona intestinalis		8 – 25	11 – 42	Jackson 2005 Bellas et al. 2003	L
Styela clava		-2 – 27	10 – 36	Cohen 2005	L
Jellyfish					
Blackfordia virginica		10 – 32	0 – 35	Vannucci et al. 1970 Moore 1987 Mills and Sommer 1995	L
Mnemiopsis leidyi		1.3 – 32	3.4 – 75	GESAMP 1997	L
Bryozoans					
Bugula flabellate		9.1 – 20.7	33.4 – 37.8	Jenkins 1986 Valdivia et al. 2005	L
Bugula neritina		9.1 – 20.7	14 – 37.8	Mawatari 1951 Jenkins 1986	L
Schizoporella errata		13 – 26.0	38.9 – 39.3	Brown et al. 2003	L
Tricellaria occidentalis		9.1 – 20.7	33.4 – 37.8	Jenkins 1986	L
Watersipora arcuata		15 – 22	No data	Wisely 1958	L
Watersipora subtorquata		12 – 28	25 – 49	Cohen 2005	L

Group/Species	Strain/Congener	Temperature °C	Salinity psu	Source(s)	Reliability
Fish					
Neogobius melanostomus		-1 – 30	0 – 40.6	Charlebois et al. 1997 Stepanova et al. 2005	L
Tridentiger bifasciatus		5 – 37	0 – 21	Matern 2001 Matern and Brown 2005	H

Table 3 - Summary for each species based on the highest and lowest values for temperature and salinity tolerances across strains, congeners and distributions. Blue = species which encompass different strains, Red = species where data are lacking, and grey background indicates low reliability of information. 'H' indicates high reliability of the data, while 'L' indicates that the species is known to occur at these levels but usually has not been tested outside these values.

Group	Species	Temperature °C	Salinity psu	Reliability
Microalgae	*Alexandrium catenella*	10 – 38	15 – 45	H
	Alexandrium minutum	10 – 30	4 – 37.5	H
	Alexandrium tamarense	2.5 – 30	7 – 40	H
	Gymnodinium catenatum	12.5 – 35	Min. 20	H
	Dinophysis norvegica	3.2 – 17.8	6 – 34	L
	Pfiesteria piscicida	4 – 31	0.5 – 60	H
	Pseudo-nitzschia seriata	-1.6 – 18	5 – 48	L
Macroalgae	*Caulerpa taxifolia*	9 – 32.5	Min. 17	H
	Codium fragile ssp. tomentosoides	-2 – 34	17.5 – 40	H
	Polysiphonia brodiaei	0 – 28	5 – 35	L
	Undaria pinnatifida	0 – 27	20 – 34	H
Echinoderms	*Asterias amurensis*	0 – 25	18.7 – 41	H
Crustaceans	*Carcinus maenas*	0 – 33	1.4 – 54	H
	Charybdis japonica	12 – 24	No data	L
	Eriocheir sinensis	7 – 30	0 – 35	L
	Hemigrapsus sanguineus	0.8 – 34	0 – 48	L
	Pseudodiaptomus marinus	8.9 – 28.2	28.6 – 32.3	L
	Balanus eburneus	16 – 32	2 – 40	L
	Balanus reticulates	6 – 44	0.5 – 40	L
	Megabalanus rosa	15 – 28	24 – 34	L
	Megabalanus tintinnabulum	Max 45	No data	H
Molluscs	*Varicorbula gibba*	-1 – 26	26 – 39	L
	Crassostrea gigas	-1.8 – 35	3 – 56	H
	Petricolaria pholadiformis	2 – 30	20 – 35	L
	Potamocorbula amurensis	0 – 28	0 – 35	L
	Musculista senhousia	-3 – 31.1	6.6 – 39	H
	Perna perna	7.5 – 30	15 – 55	H
	Limnoperna fortunei	10 – 32.6	0 – 3	L
	Mytilopsis sallei	5 – 40	0 – 50	H
	Perna viridis	6 – 37.5	0 – 64	H
	Crepidula fornicata	15 – 35	18 – 40	L
Polychaetes	*Hydroides ezoensis*	4 – 23	32 – 35	L
	Hydroides elegans	13 – 30	15 – 42	L
	Hydroides sanctaecrucis	No data	No data	
	Polydora cornuta	11 – 27	33 – 37	L
	Polydora websteri	1 – 18	27 – 32	L
	Pseudopolydora paucibranchiata	8.5 – 21	21.5 – 35	L
	Sabella spallanzanii	4 – 29	26 – 38	L
Tunicates	*Ciona intestinalis*	8 – 25	11 – 42	L
	Styela clava	-2 – 27	10 – 36	L
Jellyfish	*Blackfordia virginica*	10 – 32	0 – 35	L
	Mnemiopsis leidyi	1.3 – 32	3.4 – 75	L
Bryozoans	*Bugula flabellate*	9.1 – 20.7	33.4 – 37.8	L
	Bugula neritina	9.1 – 20.7	14 – 37.8	L
	Schizoporella errata	13 – 26	38.9 – 39.3	L
	Tricellaria occidentalis	9.1 – 20.7	33.4 – 37.8	L
	Watersipora arcuata	15 – 22	No data	L
	Watersipora subtorquata	12 – 28	25 – 49	L
Fish	*Neogobius melanostomus*	-1 – 30	0 – 40.6	L
	Tridentiger bifasciatus	5 – 37	0 – 21	H

7 SUMMARY

There would appear to be little need to include *Limnoperna fortunei* in port and harbour surveys in all marine harbours, as this species seems to be restricted to freshwater (< 3 psu; Table 2) and is widely described as such (Darrigran 2002; Brugnoli *et al.* 2005; Sylvester *et al.* 2005). Apart from *Pseudo-nitzschia seriata*, which appears to be restricted to waters less than 18 °C (although note the low reliability of this estimate, Table 2), all other microalgae may be retained as they have wide ranging tolerances, particularly given the level of flexibility exhibited across different strains (Table 2). Given that sampling for microalgae will be very similar in most instances, the inclusion of all dinoflagellates and diatoms as a generic component of pest surveys may not be prohibitive.

Sampling for *Caulerpa taxifolia* in northern Australia is probably unnecessary as this species occurs naturally in tropical waters, albeit as the non-invasive wild form (Cheshire *et al.* 2002). Otherwise, macroalgae may be difficult to distinguish from native species, a factor exacerbated by the high diversity of the southern Australian marine flora (Cheshire *et al.* 2000).

For economically important and/or well-known pests, reliability of the data is generally high (Tables 2 and 3). These include most of the dinoflagellates and macroalgae, *Asterias amurensis, Carcinus maenas, Crassostrea gigas, Musculista senhousia, Perna perna, Mytilopsis sallei, Perna viridis, Megabalanus tintinnabulum,* and *Tridentiger bifasciatus*. For all other species (32 in total; Table 3), reliability of the information has to be given as low, owing to lack of scientifically rigorous data. Based on the application of a precautionary principal to marine pest survey design, the argument for the blanket inclusion of most, if not all, of this latter group should be considered.

Bryozoans would appear to be generally limited to water temperatures higher than 10 °C and are intolerant of low salinities (Table 2 andTable 3). However, in all bryozoan species, the reliability of the information is low. Otherwise there is no pattern to temperature and salinity tolerances amongst the other groups (along with the single echinoderm and mollusc; Table 2 and 3). Each pest species must therefore be considered individually for each survey, not only in terms of both the temperature and salinity tolerances but also taking into account the reliability of the available information.

For many priority pest species, an experimental investigation of temperature and salinity tolerance should be relatively straightforward.

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