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Pathogens and Parasites of the Mussels *Mytilus galloprovincialis* and *Perna canaliculus*: Assessment of the Threats Faced by New Zealand Aquaculture

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Pathogens and Parasites of the Mussels *Mytilus galloprovincialis* and *Perna canaliculus*: Assessment of the Threats Faced by New Zealand Aquaculture

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EXECUTIVE SUMMARY

The literature on pathogens and parasites of the mytilid genera *Mytilus* and *Perna* was surveyed with particular focus on *M. galloprovincialis* and *P. canaliculus*. Likely pathological threats posed to New Zealand mussel aquaculture were identified and recommendations were discussed under the following topics.

Epidemiological differences between New Zealand *Mytilus* and *Perna*
There is a paucity of data for this comparison. Comparability or otherwise would inform predictions as to the threat posed by overseas *Mytilus* parasites to New Zealand *Perna* and *vice versa*. Samples of *P. canaliculus* and *M. galloprovincialis* should be surveyed to establish any significant difference in parasite loads or pathology.

Invasive dynamics and possible development of pathological threat
The greatest potential threat to New Zealand *Perna canaliculus* aquaculture appears to be posed by parasites introduced by invading *Mytilus* species. These common ship-borne fouling organisms are a likely source of overseas pathogens, the most important of which are probably *Marteilia* spp. and disseminated haemic neoplasia. Hybridisation of invasive and local mussels presents a further potential pathology hazard by production of a more susceptible reservoir host thus giving the potential for production of more infected hosts and greater water load of transmission stages. Such an increase in transmission stages might be a cause of concern for *Perna canaliculus* whose susceptibility is currently unknown. Studies on *Marteilia* and haemic neoplasia are required to address the following questions: Is *Perna canaliculus* susceptible to either of these pathogens? What are the current prevalences of these pathogens in local *mytilids*? What species of mussels are entering New Zealand waters? Do they include *Mytilus* spp. other than *M. galloprovincialis*? Is there any evidence for *Mytilus* hybridisation? Are there are higher prevalences of neoplasia in ports and harbours and around areas of higher pollution stress?

Significant threats posed by other New Zealand shellfish parasites to overseas shellfish
These include New Zealand *Bonamia exitiosa,* mycoplasmosis and *Perkinsus olseni.* These are of concern as they are either OIE (*Office International des Epizooties)* listed or of unassessed pathological threat to non-New Zealand molluscs. It is recommended that extra effort be expended to exclude New Zealand molluscs harbouring these from shipments of Greenshell™ mussels; New Zealand export molluscs should be free of these diseases, and the threat of these diseases to recipient countries should be assessed.

The threat of New Zealand molluscan parasites to NZ export markets
Most recorded pathogens in New Zealand mussels are also resident in major importing countries. The following are exceptions in some cases. *Enterogonia orbicularis* is of minor significance in New Zealand but consideration should be given to its destructive potential in overseas mussel populations, assessment should be made of current numbers occurring in export mussels (if any) and appropriate measures instituted as necessary. An unenveloped RNA virus of the digestive system occurs in scallops and clams in New Zealand, and in other molluscs worldwide. Since infections have been

associated with moderate to severe mortalities, appropriate measures are required when exporting mussels to countries where this virus has not been reported. The apicomplexan APX has been found in mussels from the Marlborough Sounds and poses a potential threat to other mussels and oysters. For both APX and the digestive virus, assessment should be made of the susceptibility of *M. galloprovincialis*, and local *Mytilus galloprovincialis* should be surveyed for infections. Furthermore, consideration should be given to purification and sequencing of these pathogens for identification and detection.

Other potential health hazards

Birnaviruses can exploit mytilids which can then act as reservoirs in areas of culture in proximity with finfish. Surveying for these viruses should be performed where mussels are cultured in proximity to populations of susceptible finfish.

Management of perceived threats

Overseas regulatory agencies can use such pathogens to argue for non-tariff trade barriers with the onus on New Zealand to refute them. In consequence, credible policies should be formulated for managing the risk (such as it is) that our pathogens pose to overseas customers, we should also stay abreast of current acceptable import standards.

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1. INTRODUCTION – PURPOSE OF THE REVIEW

Literature has been surveyed on the worldwide occurrence and distribution of pathogenic organisms associated with mytilids belonging to *Mytilus* and *Perna*. Emphasis is placed on the New Zealand representatives of these genera - *Perna canaliculus* (Greenshell™ mussel or GSM) and *Mytilus galloprovincialis* (blue mussel) [*M. galloprovincialis* is the usage recommended by Gardner (2004) after multivariate morphometric analyses of fossil, midden and contemporary New Zealand blue mussels].

The survey seeks to assess any disease threat, local or overseas, that could impact on the New Zealand GSM industry. This would include direct risks from indigenous pathogens, the threat posed by potential invaders, and the threat posed to trade by presence of significant pathogens in exported GSMs. The review will cover: significant members of the reported parasite fauna of New Zealand mussels and other local molluscs, overseas parasites that pose a threat to New Zealand mussels, and other potential pathology/health hazards.

Tables 1 to 6 list all the agents and conditions found in the literature. Of these, significant threats are selected in Section 2, their significance and suggestions for management given in Section 3.

2. IDENTIFICATION OF PATHOLOGICAL THREATS

2.1. OIE notifiable mytilid diseases

OIE (formerly *Office International des Epizooties*) is now known as the World Organisation for Animal Health. This intergovernmental organisation is responsible for improving animal health worldwide and has significant interest in molluscs. They have compiled a list of important molluscan diseases (Table 1).

Table 1. Listed OIE notifiable molluscan diseases.

Disease	Present in New Zealand?	In New Zealand mytilids?
Bonamiosis	Yes (Diggles *et al.* 2002)	Unreported
Haplosporidiosis	Yes (Diggles *et al.* 2002)	Unreported
Marteiliosis		Unreported
Marteilioides		Unreported
Mikrocytosis		Unreported
Perkinsosis	Yes (Diggles *et al.* 2002)	Unreported

2.1.1. OIE notifiable diseases in New Zealand Mussels

Representatives of three of these disease genera are reported in New Zealand but none from New Zealand mytilids. See Table 2 for specific details below of the diseases and their hosts in New Zealand.

2.1.2. Mytilid infecting OIE notifiable diseases and their relatives occurring overseas (see Table 2)

***Bonamia*-like microcell organisms**

One infection is reported in *M. edulis* (Figueras *et al.* 1991) causing an intense haemocyte response.

Haplosporidia

Representative haplosporidia include: *Haplosporidium tumefacientis* in *M. californianus* (Taylor 1966; Sprague 1970; VPS 2000; BA 2002); *Haplosporidium* sp. in *M. edulis* (Burreson & Ford 2004) and in *M. galloprovincialis, M. edulis* and *M. californianus* (Bower 2001a); and *Haplosporidium* sp. in *M. galloprovincialis* (Comps & Lopez-Gomez 1992). According to Bower (2001a) haplosporidian infections in mussels are of low prevalence. *Haplosporidium* sp. was reported in one infection of *M. edulis* (Figueras *et al.* 1991) showing no host response. A report of *Minchinia* sp. in *M. galloprovincialis* (Comps & Tigé 1997) was associated with emaciation but at low prevalence.

***Marteilia* spp. (Paramyxea)**

Marteilia refringens (Aber disease) has been reported in *M. edulis* (Hine 1996; Diggles *et al.* 2002), in *M. galloprovincialis* (Villalba *et al.* 1993, 1997; Fuentes *et al.* 1995; Robledo & Figueras 1995; Bower 2006a) and in both *M. edulis* and *M. galloprovincialis* (Pérez Camacho *et al.* 1997; VPS 2000; BA 2002). *Marteilia maurini* has been reported in *M. galloprovincialis* (Comps *et al.* 1982; Bower 2006) and both *M. edulis* and *M. galloprovincialis* (Zrnčić *et al.* 2001; BA 2002). *Marteilia* sp. has been reported in *M. galloprovincialis* (Zrnčić *et al.* 2001) and both *M. edulis* and *M. galloprovincialis* (Longshaw *et al.* 2001). Bower (2006) reports *Marteilia* as a cause of significant mortality in mussels.

2.2. Other significant diseases of mussels (see Tables 3 and 6)

2.2.1. Diseases/pathogens reported in New Zealand mussels (see Table 4)

Previous surveys suggest that *Perna canaliculus* in New Zealand faces no great pathological threat. Hine (1989) reported no disease-associated mortalities in *P. canaliculus*. Similarly, Hine (1996) includes no listed serious or potentially serious pathogens in New Zealand *Mytilus* spp. or *P. canaliculus*. And although Hine (1997) reported mortalities in aquaculture *P. canaliculus* of 50 to 100% associated with virus-like particles and digestive tubule damage, a suite of other parasites were also mentioned, none of which were deemed a serious cause of mortality. Further, Hine (2002a) reports that mussels examined from the Marlborough Sounds

and Coromandel appeared to be in good health overall despite recording low levels of apparent digestive viral infection. Jeffs *et al.* (1999) echoes these reports when he cites mortality problems associated with an unenveloped RNA virus as of greatest concern in *P. canaliculus* and that, of several other parasites found, none cause significant mortalities.

Digestive epithelial virosis

The unenveloped RNA virus appears to be the cause of digestive epithelial virosis (Diggles *et al.* 2002), a condition that also affects scallops and clams in New Zealand and other molluscs elsewhere. Such viruses have been identified (Jones *et al.* 1996; Diggles *et al.* 2002; Renault & Novoa 2004; Renault 2006) as causing a mytilid viral problem in New Zealand *Mytilus galloprovincialis* and *Perna canaliculus*. Infections are, in some cases, associated with moderate to severe mortalities. Besides being found in other New Zealand molluscs, similar viruses have been reported in Australia, Scotland, Denmark, and elsewhere (Bower 2001e).

Enterogonia orbicularis

This flatworm is a predator of *Perna canaliculus* in New Zealand waters but is not of great importance – outbreaks are often associated with poor husbandry (Diggles *et al.* 2002).

Apicomplexan X (APX)

Also referred to as coccidiosis in Hine (1994), this agent is reported from New Zealand only, where it occurs in mussels from the Marlborough Sounds and in flat oysters from all around the coast (Diggles *et al.* 2002; Hine 2002b).

2.2.2. Significant mytilid diseases/pathogens reported overseas (see Table 4)

Disseminated haemic neoplasia

This condition can be transmitted by cohabitation (Bower 2006b). A viral cause is discussed by Renault (2006) and Renault & Novoa (2004). It is reported at prevalences of 4 to 40% with mortalities of ~75% - larger mussels appear to be more affected. Hybrids of *M. edulis* and *M. galloprovincialis* (Fuentes *et al.* 2002) have been reported with much higher prevalences of this condition than pure species. In consequence, they discuss the possibility that hybridisation lowers host resistance.

***Mytilicola* spp.**

The copepod *Mytilicola intestinalis* in *M. edulis* and *M. galloprovincialis* appears (Bower 2001d) to degrade condition rather than inflict serious mortality. Similarly, *Mytilicola orientalis* occurring in *M. trossulus, M. galloprovincialis, M. edulis, M. californianus* and *M. crassitesta* (Bower 1996a) is of minimal pathological impact.

2.3. Other New Zealand shellfish parasites and the threats posed to overseas shellfish (see Tables 2 and 5)

Herpes virosis (OsHV-1)

In New Zealand, (OsHV-1) has been reported in *Crassostrea gigas* and *Ostrea chilensis* (Diggles *et al.* 2002). The virus is associated with significant larval mortalities in hatcheries, and is of worldwide distribution.

Bonamia exitiosa

This *Bonamia* species is limited to New Zealand where it occurs in *Ostrea chilensis* (Diggles *et al.* 2002) causing significant to severe mortalities in adult oysters.

Perkinsus olseni

In New Zealand this *Perkinsus* sp. is reported in *Austrovenus stutchburyi, Macomona liliana, Barbatia novaezelandia* and *Paphies australis* (Diggles *et al.* 2002) but it causes no gross signs in these bivalves. In raised water temperatures the (apparently) same *Perkinsus* species can be pathogenic in the Australian abalone *Haliotis rubra*.

Mycoplasmosis

This condition has been found in adult New Zealand scallops *Pecten novaezelandiae* and probably occurs all around the coast. A similar condition is found in Canadian scallops (Diggles *et al.* 2002).

Rickettsiosis

Crassostrea gigas, Ostrea chilensis, Pecten novaezelandiae, Austrovenus stutchburyi, and *Saccostrea glomerata* harbour infections (Diggles *et al.* 2002). Molluscan rickettsioses are cosmopolitan.

2.4. Other potential health hazards

Anisakids (Nematoda)

Despite the assertion by Bower & Figueras (1989) that parasitic nematodes are rarely found in mussels, they report an infection by the anisakid *Phocanema* (*Pseudoterranova*) *decipiens* infection in a North Atlantic *M. edulis.* Although rare, this case is noteworthy because *Pseudoterranova* spp. is a facultative human parasite. After *Anisakis* spp., *Pseudoterranova* spp., are the next most frequently reported agents of human anisakidosis (Smith 1999) – human cases occur worldwide.

Aquatic birnaviruses

The aquabirnavirus Infectious Pancreatic Necrosis virus (IPNV) has been detected in *M. edulis* (VPS 2000). It is a common virus of salmonids and is also a suspected clam pathogen in Taiwan. Similarly, Kitamura *et al.* (2007) report finding an aquatic birnavirus (ABV) in *M. galloprovincialis* where the mussel was acting as a reservoir host for infections in the Japanese flounder *Paralichthys olivaceous*. Caution is clearly required in polyculture, as mytilids might harbour such viruses with consequent threat to susceptible fish.

Table 2. OIE list genera.
References in the **pathogen** column refer to the named pathogens. Citations in the **host** columns specify references associating the pathogen with the named host.

Pathogen	Overseas host	New Zealand host
Bonamia ostreae	Many ostreids (IFREMER 1998; OIE 2000; Diggles *et al.* 2002; Raidal *et al.* 2004). Figueras Robledo (1994) found that *Bonamia ostreae* does not infect *Mytilus galloprovincialis*	
Bonamia exitiosa	*O. angasi* (OIE 2006)	*Ostrea chilensis* (Diggles *et al.* 2002)
Microcell -like organism	*M. edulis* (Figueras *et al.* 1991)	
Haplosporidium tumefacientis	*M. californianus* (Taylor 1966; Sprague 1970; VPS 2000; BA 2002)	
Haplosporidium sp.	*M. edulis* (Figueras *et al.* 1991; Burreson & Ford 2004), *Mytilus* spp. (Bower 2001a)	
Haplosporidium costale	*C. virginica* (Raidal *et al.* 2004)	
Haplosporidium nelsoni	*C. virginica* (IFREMER 1998), *C. virginica, C. gigas* (OIE 2000; Diggles *et al.* 2002; Raidal *et al.* 2004)	
MSX haplosporidian	*M. galloprovincialis* (Comps & Lopez-Gomez 1992)	
Minchinia sp.	*M. galloprovincialis* (Comps & Tigé 1997; VPS 2000; Burreson & Ford 2004)	
Marteilia sydneyi	*Sacccostrea glomerata* (Diggles *et al.* 2002)	
Marteilia refringens	*M. edulis, M. galloprovincialis.* (Pérez Camacho *et al.* 1997; VPS 2000; BA 2002). *M. edulis* (Hine 1996; Diggles *et al.* 2002). *M. galloprovincialis* (Fuentes *et al.* 1995; Robledo & Figueras 1995; Villalba *et al.* 1997, 1993; Bower 2006a)	
Marteilia maurini	*M. galloprovincialis* (Comps *et al.* 1982; Bower 2006a). *M. edulis, M. galloprovincialis* (Zrnčić *et al.* 2001).	
Marteilioides chungmuensis	*C. gigas, Saccostrea echinata* (Diggles *et al.* 2002)	
Marteilia sp.	*M. galloprovincialis* (Zrnčić *et al.* 2001). *M. edulis, M. galloprovincialis* (Longshaw *et al.* 2001)	
Mikrocytos mackini Denman Island disease	Ostreids (Raidal *et al.* 2004)	
Mikrocytos roughleyi	*Saccostrea glomerata* (Diggles *et al.* 2002)	
Perkinsus olseni	*Haliotis* spp., *Ruditapes philipinarum* (BA 2002). *Haliotis rubra* (Diggles *et al.* 2002)	*Austrovenus stutchburyi*, *Macomona liliana, Barbatia novaezelandia Paphies australis*, (Diggles *et al.* 2002)
Perkinsus marinus	*Crassostrea* spp. (Raidal *et al.* 2004) and some clams (Diggles *et al.* 2002)	

Table 3. Other (non OIE listed) pathogens in *Mytilus* spp. *Perna* spp. and other significant mytilids overseas. References in the **pathogen** column refer to the named pathogens. Citations in the **host** column specify references associating pathogen with the named host. In addition, general taxonomic and biological references for each pathogen group are placed in the left hand column.

Pathogen		Host
Viruses	Disseminated haemic neoplasia – viral cause?	*M. edulis* (Elston *et al.* 1988a; Elston *et al.* 1988b; Bower 1989; Kent *et al.* 1989; Elston 1990; Noël *et al.* 1991). *M. galloprovincialis, M. edulis, M. trossulus, M. chilensis* (Ciocan & Sunila 2005; Bower 2006b). *Mytilus trossulus* (Gee *et al.* 1994). *Mytilus* sp. (Moore *et al.* 1991). *M. edulis* x *M. galloprovincialis* hybrids (Fuentes *et al.* 2002).
	Neoplasia (Barber 2004)	*Mytilus edulis* (Cosson-Mannevy *et al.* 1984; Green & Alderman 1983; Rasmussen 1986b)
	Digestive epithelial virosis: picorna-like virus associated with granulocytomas	*M. edulis* (Rasmussen 1986a)
Bacteria	*Nocardia crassostreae* (Pacific oyster nocardiosis)	*M. edulis* unconfirmed (BA 2002; Diggles *et al.* 2002)
	Gill rickettsiae	*Aulacomya atra* (Cremonte *et al.* 2005)
	Intestinal rickettsiae, gill bacteria	*M. edulis* (Cremonte *et al.* 2005)
	Digestive rickettsiae	*M. edulis* (Figueras *et al.* 1991)
	Rickettsia-like and *Chlamydia*-like Organisms	*M. trossulus, M. galloprovincialis, M. californianus, M. edulis* (Bower 2004a). *M. edulis* (Gulka & Chang 1984).
	Prokaryotic inclusion bodies (PIB).	
	Intracellular rickettsiae and chlamydiae	*M. californianus, M. edulis* (Bower & Figueras 1989)
	Rickettsia-like organisms (RLO) of digestive gland	*M. edulis* (Figueras *et al.* 1991)
	Procaryotic inclusions: gill and digestive gland	*M. galloprovincialis* (Villalba *et al.* 1997)
Blue green algae (Fogg 1973; Fogg *et al.* 1973; Carr, Whitton 1973; Komárek, Anagnostidis 1998; Geitler 1985; Ghirardelli 2002). For general reviews of endolithic organisms: (Kobluk, Risk 1977; Kinne 1983)	*Mastigocoleus* sp. (Anand 1937; Mao Che *et al.* 1996; Humm, Wicks 1980)	*P. perna, M. galloprovincialis*, *Choromytilus meridionalis* (Webb & Korrûbell 1994)
	Hyella caespitosa (Mao Che *et al.* 1996). *Hyella gigas* (Mao Che *et al.* 1996). *Mastigocoleus testarum* (Mao Che *et al.* 1996). *Phormidium* sp. (Raghukmar *et al.* 1991). *Plectonema terebrans* (Mao Che *et al.* 1996)	*P. viridis* (Raghukmar *et al.* 1991)
	Plectonema terebrans(Mao Che *et al.* 1996), *Mastigocoleus testarum* (Le Campion Alsumard *et al.* 1995; Mao Che *et al.* 1996), *Hyella caespitosa* (Mao Che *et al.* 1996), *Pleurocapsa* sp. (Kaehler & McQuaid 1999)	*P. perna* (Kaehler & McQuaid 1999; Kaehler 1999)
	Microcystis sp.	*M. edulis* (Bower 1992).
Fungi	Fungi: shell deformity and condition loss	*M. edulis* (Bower & Figueras 1989)
	Mycotic Periostracal Sloughing	*M. edulis* (Bower 2004b)
	Fungal infection (unidentified).	*M. galloprovincialis* (Franchini *et al.* 2005) byssus loss and impact on farming yield. Damage to foot musculature, byssus organ and digestive gland

Table 3. (continued).

	Pathogen	Host
Lichens	*Arthropyrenia sublitoralis*	*M. edulis* (Bower 1992)
Chlorophytes	*Coccomyxa parasitica*	*M. edulis chilensis* (Gray *et al.* 1999)
	Gomontia sp.	*P. viridis* (Raghukmar *et al.* 1991)
Protozoa	*Ancistrum mytili*	*M. edulis* (Fenchel 1965; Figueras *et al.* 1991). *M. edulis, Mytilus* spp. (Bower 2001b) *M. edulis* (Teia dos Santos & Coimbra 1995). *M. galloprovincialis* (Rayyan *et al.* 2006)
	Chytripiopsis (Steinhausia) mytilovum.	*M. galloprovincialis* (Jones & Creeper 2006; Villalba *et al.* 1997). *M. edulis, M. galloprovincialis* (Sprague 1970; Bower 1992). *Mytilus* spp. (Hillman 1991; Comtet *et al.* 2004; Bower 2007). *M. edulis* (Figueras *et al.* 1991)
	Conchophthirius mytili	*M. edulis* (Teia dos Santos & Coimbra 1995)
	Crebricoma carinata, C. kozloffi	*M. edulis* (Fenchel 1965)
	Gargarius gargarius	*M. edulis* (Fenchel 1965)
	Gargarius gargarius, and other unidentified *Sphenophrya*-like ciliates	*Mytilus* spp. (Bower & McGladdery 2001c)
	Gregarines: *Nematopsis schneideri, Nematopsis legeri, Nematopsis* spp., *Porospora galloprovincialis, Porospora gigantea etc*.	*M. edulis, M. trossulus, M. galloprovincialis* (Bower & McGladdery 2001a)
	Nematopsis legeri	*M. galloprovincialis* (Sprague 1970)
	Nematopsis schneideri	*M. edulis* (Sprague 1970)
	Isocomides mytili	*M. galloprovincialis* (Kinne 1983)
	Mytilophilus pacifica	*M. californianus* (Antipa & Dolan 1985; Bower 1992)
	Intracellular Rhynchodid-like Phyllopharyngea ciliates	*M. edulis, M. trossulus, M. galloprovincialis* (McGladdery & Bower 2002)
	Peniculostoma mytili	*M. edulis* (Fenchel 1965; Bower 1992)
	Protistan in digestive ducts	*M. galloprovincialis* (Villalba *et al.* 1997)
	Pseudoklossia semiluna n. sp.	*Mytilus* spp. (Desser *et al.* 1998)
	kidney coccidia including *Pseudoklossia semiluna* n. sp	*M. galloprovincialis* (Villalba *et al.* 1997) *M. edulis/galloprovincialis/trossulus* (Bower 2001c)
	Raabela helensis	*M. edulis* (Fenchel 1965)
	Steinhausia sp. (Lee *et al.* 2000)	*M. galloprovincialis* (Jones 1997)
	Other ciliates	*M. edulis, Aulacomya atra* (Cremonte *et al.* 2005)
	Gill ciliates	*M. galloprovincialis* (Villalba *et al.* 1997)
	Digestive ciliate	*M. edulis* (Figueras *et al.* 1991)
	Intracellular cilates in digestive tubules	*M. galloprovincialis* (Villalba *et al.* 1997)
Porifera	*Cliona* sp.	*M. edulis* (BA 2002)
	Cliona celata, Cliona lobata	*M. edulis* (Bower 1992)
	Cliona vastifica	*M. galloprovincialis* (Bower 1992)
Mesozoa	*Stoecharthum* sp.	*M. edulis* (Bower 1992)

Table 3. (continued).

	Pathogen	Host
Hydroids (Kubota 1978, 1979, 1983, 1984, 1985abc, 1987abc, 1989, 1991, 2000)	*Eugymnanthea inquilina* (Piraino *et al.* 1994)	*M. galloprovincialis* (Rayyan *et al.* 2004, 2002)
	Eugymnanthea spp. (Govindarajan *et al.* 2005)	*M. galloprovincialis* (Govindarajan *et al.* 2005)
	Eugymnanthea spp. *Eucheilota* ssp.	*M. galloprovincialis*, *M. edulis*, *M. coruscus* (Bower & Rayyan 2007)
	Eucheilota intermedia	*M. edulis* (Bower 1992)
	Eutima japonica	*M. edulis* (Bower 1992)
Helminths	*Cercaria noblei*	*M. californianus* (Bower 1992)
	Cercaria praecox	*M. edulis* (Pregenzer 1983)
	Cercaria tenuans, Bucephalus mytili	*M. edulis* (Cole 1935)
	Cercaria tenuans	*M. edulis* (Canzonier 1972)
	Gymnophallus sp.	*M. edulis* (Pregenzer 1983)
	Other cercariae and metacercariae	*M. galloprovincialis, Perna perna, Choromytilus meridionalis, Aulacomya ater* (Webb 1999). *M. edulis* (Loos–Frank 1971). *M. galloprovincialis, M. edulis* (Bower 1992). *M. californianus*, *M. galloprovincialis* (Lauckner 1984; Caceres-Martinez & Vasquez-Yeomans 1999). *Mytilus platensis* (Morris 1976)
	Psilostomum brevicolle metacercariae	*M. edulis* (Loos-Frank 1968)
	Renicola roscovita	*M. edulis* (Svärdh & Thulin 1985; Thieltges 2006)
	Renicola thaidus metacercaria	*M. edulis* (Stunkard 1964)
	Prosorhynchus crucibulum	*M. edulis* (Matthews 1973; Teia dos Santos & Coimbra 1995)
	Prosorhynchus squamatus	*M. edulis* (Coustau *et al.* 1991, 1993; McGladdery *et al.* 1999). *M. edulis, M. galloprovincialis* (Bower 1992) *M. edulis-M. galloprovincialis* complex (Coustau *et al.* 1990)
	Other bucephalids (Stunkard 1974)	*Choromytilus chorus* (Lasiak 1991). *C. meridionalis* (Webb 1999). *P. perna* (Umiji *et al.* 1976; Lasiak 1993; Calvo-Ugarteburu & McQuaid 1998; da Silva *et al.* 2002). *Mytilus platensis* (Bower 1992) *M. edulis*, *M. galloprovincialis* and others (Bower & McGladdery 2001b)
	Paratimonia gobii	*M. galloprovincialis* (Bartoli 1984)
	Parvatrema dubosi	*M. galloprovincialis* (Bartoli 1984; Machkevsky 1989)
	Proctoeces maculatus	*M. galloprovincialis* (Bartoli 1984; Robledo *et al.* 1994a; Villalba *et al.* 1997; Rayyan *et al.* 2004). *M. edulis* (Stunkard & Uzmann 1959; Lang & Dennis 1976; Bray 1983; Feng 1988; Figueras *et al.* 1991; Teia dos Santos & Coimbra 1995; Sunila *et al.* 2004)
	Proctoeces spp. (Bray 1983)	*P. perna* (Lasiak 1989; Calvo-Ugarteburu & McQuaid 1998)
	Turbellarian in intestinal lumen	*M. galloprovincialis* (Villalba *et al.* 1997)
	Urastoma cyprinae gill turbellaria	*M. edulis* (Teia dos Santos & Coimbra 1995), *M. galloprovincialis* (Murina & Solonchenko 1991; Robledo *et al.* 1994b; Villalba *et al.* 1997; Canestri Trotti *et al.* 1998; Rayyan *et al.* 2004). *M. galloprovincialis, M. californianus* (Caceres-Martinez *et al.* 1998) *Mytilus californianus*, *Mytilus galloprovincialis* (Caceres-Martinez *et al.* 1998). *M. edulis*, *M. galloprovincialis* (Bower 2001f)
	Polydora haswelli, P. hoplura, P. websteri	*M. edulis* (Pregenzer 1983)

Table 3. (continued).

	Pathogen	Host
Helminths	*Polydora ciliata*	*Mytilus edulis* (Kent 1979, 1981; Ambariyanto & Seed 1991; Bower *et al.* 1994). *M. galloprovincialis* (Murina & Solonchenko 1991)
	Boccardia chilensis, B. polybranchia	*M. edulis* (Pregenzer 1983)
	Tylocephalum sp.	*M. edulis* (Bower 1992)
Decapoda	*Tumidotheres* (=*Pinnotheres*) *maculatus* (Pearce 1964). *Pinnotheres pisum*, *P.* spp., *Fabia subquadrata*	*M. edulis*, *M. californianus* (Bower 1996b)
	Tumidotheres maculatus	*M. edulis* (Tablado & Gappa 1995). *Aulacomya atra* (Cremonte *et al.* 2005)
	Pinnotheres hickmani	*M. edulis* (Pregenzer 1983)
	Pinnotheres sinensis	*M. galloprovincialis* (Sun *et al.* 2006)
	Pinnotheres pisum	*M. edulis* (Haines *et al.* 1994)
Copepoda	*Modiolaria gracilis*	*M. galloprovincialis, M. californianus* (Caceres-Martinez *et al.* 1996, Caceres-Martinez, Vasquez-Yeomans 1999)
	Mytilicola intestinalis (Hockley 1951)	*M. galloprovincialis* (Robledo *et al.* 1994a, c; Fuentes *et al.* 1995: Villalba *et al.* 1997; Canestri Trotti *et al.* 1998; Rayyan *et al.* 2004). *M. edulis, M. galloprovincialis.* Bower (2001d; BA 2002). *M. edulis* (Dare 1977)
	Mytilicola orientalis	*M. edulis* (Bernard 1969). *M. trossulus, M. galloprovincialis, M. edulis, M. californianus, M. crassitesta* (Bower 1996a)
	Pseudomyicola spinosus	*M. galloprovincialis, M. californianus* (Caceres-Martinez *et al.* 1996). *M. edulis* (Pregenzer 1983) *Mytilus* sp. (Humes 1968)
	Myicola sp.	*M. edulis* (Pregenzer 1983)
	Edotea magellanica	*M. chilensis* (Jaramillo *et al.* 1981; Cremonte *et al.* 2005)
	Modiolicola bifidus	*M. edulis* (Teia dos Santos & Coimbra 1995)
	Ostrincola similis	*P. viridis* (Lin & Ho 1999)
	Anthessius mytilicolus	*P. viridis* (Lin & Ho 1999)
	Lichomolgus uncus	*M. edulis* (Pregenzer 1983)
Pycnogonida (Stock 1959; King 1973; Kikuchi 1976; Ogawa & Matsuzaki 1985; Arnaud & Bamber 1987; Child 1996)	*Nymphonella* sp. (Oshima 1927, 1933a, b, 1935, 1938)	*Choromytilus meridionalis*, *Semimytilus algosus* (Webb 1999)
	Nymphon gracile	*M. edulis* (Lintas & Seed 1994)
	Achelia chelata	*M. californianus* (Benson & Chivers 1960; Ricketts & Calvin 1968 cited in Lauckner 1983)

Table 4. Parasites reported in New Zealand mussels.
References in the **Pathogen** column refer to the named pathogens. Citations in the **New Zealand hosts** column specify references associating the pathogen with the named host.

Pathogen	New Zealand host
Digestive epithelial virosis or virus-like disease	*P. canaliculus* (Diggles *et al.* 2002), *P. canaliculus, M. galloprovincialis* (Jones *et al.* 1996; Hine 1997; Bower 2001e)
Gill discoloration syndrome	*P. canaliculus* (Diggles *et al.* 2000)
Plectonema, Mastigocoleus, Cyanosaccus, Pleurocapsa, Hyella (Lukas & Golubic 1981, 1983; Nielsen 1987;; Le Campion Alsumard *et al.* 1995; Mao Che *et al.* 1996; Kaehler 1999; Kaehler & McQuaid 1999).	*P. canaliculus* (Webb pers obs)
Epicladia chlorophyte (Nielsen 1987)	*P. canaliculus* (Webb pers obs) in empty shells
Orchitophryid ciliates (Elston *et al.* 1999)	*P. canaliculus* (Webb pers obs)
Other Ciliates	*P. canaliculus* (Webb pers obs; Hine 2002a)
Nematopsis sp.	*P. canaliculus* (Jones 1975b; Hine 1997)
Apicomplexan X	*P. canaliculus* (Diggles *et al.* 2002 as APX; Hine 2002b as apicomplexan)
Coccidian	*P. canaliculus* (Webb pers obs)
Inclusions in digestive epithelium of mussels	(Webb pers obs) spherical inclusions similar to those described (Humphrey & Norton 2005) as intranuclear inclusion bodies in *Pinctada maxima*
Cliona	*P. canaliculus M. galloprovincialis* (Webb pers obs)
Paravortex sp.	*P. canaliculus* (Hine 2002a)
Enterogonia orbicularis	*P. canaliculus* (Diggles *et al.* 2002)
Cercaria sp. *(Bucephalus)*	*P. canaliculus* (Jones 1975a; Haswell 1903)
Cercaria haswelli (larva of *Tergestia agnostomi*)	*P. canaliculus* (Angel 1960; Hickman 1978, Hine & Jones 1994). *M. galloprovincialis, P. canaliculus* (Hine 1997), *P. canaliculus, M. edulis aoteanus* (Jones 1975a). Adult worms are reported in the mugilid fish *Aldrichetta forsteri* (Jones 1978)
Boccardia spp.	*P. canaliculus* (Diggles *et al.* 2002)
Polydora haswelli	*P. canaliculus* (Read & Handley 2004)
Cryptophialus (*Australophialus*) *melampygos*	*P. canaliculus* (Batham & Tomlinson 1965)
Lichomolgus uncus	*P. canaliculus* (Jones 1975a; Jones 1976; Hine 2002a) as *Lichomolgus* sp. (Hine 1997)
Pseudomyicola spinosus (Dinamani & Gordon 1974)	*P. canaliculus* (Hine 1997, 2002a), *P. canaliculus; M. edulis aoteanus* (Jones 1975a)
Pinnotheres sp.	*P. canaliculus, M. galloprovincialis* (Hine 1997). *M. edulis aoteanus* (Jones 1975a)
Pinnotheres novaezelandia	*P. canaliculus* (Jones 1975a; Hickman 1978). *M. galloprovincialis* (Scott 1961)

Table 5. Other significant mollusc diseases extant in New Zealand.

Pathogen	New Zealand host
Herpes virosis	*Crassostrea gigas Ostrea chilensis* (Diggles *et al.* 2002)
Mycoplasmosis	*Pecten novaezelandiae* (Diggles *et al.* 2002)
Rickettsiosis	*Crassostrea gigas, Ostrea chilensis, Pecten novaezelandiae, Austrovenus stutchburyi, Saccostrea glomerata* (Diggles *et al.* 2002)

Table 6. Threats posed by overseas parasites to New Zealand *P. Canaliculus* and *M. galloprovincialis.*

Pathogen	Host
Bonamia-like organisms	*M. edulis* (Figueras *et al.* 1991)
Haplosporidium tumefacientis	*M. californianus* (Sprague 1970; VPS 2000; BA 2002)
Haplosporidium sp.	*M. edulis* (Figueras *et al.* 1991). *M. galloprovincialis, M. edulis M. californianus* (Bower 2001a). *M. galloprovincialis* (Comps & Lopez-Gomez 1992)
Minchinia sp.	*M. galloprovincialis* (Comps & Tigé 1997)
Marteilia refringens	*M. edulis, M. galloprovincialis* (VPS 2000; BA 2002). *M, edulis* (Hine 1996; Diggles *et al.* 2002). *M. galloprovincialis* (Villalba *et al.* 1997)
Marteilia maurini	*M, edulis, M. galloprovincialis* (BA 2002). *M. galloprovincialis* (Comps *et al.* 1982)
Marteilia sp.	*M. galloprovincialis* (Zrnčić *et al.* 2001)

3. DISCUSSION AND RECOMMENDATIONS

3.1. The cosmopolitan threat of parasites to New Zealand *Perna canaliculus* production

Based on the current review *Marteilia* spp. and disseminated haemic neoplasia were determined as the most likely overseas threats to *Perna canaliculus*. Possible consequences following introduction of hosts with these conditions and possible pathways by which more susceptible hosts could emerge are discussed below.

3.1.1. Relative susceptibility of P. canaliculus *and* M. galloprovincialis *to pathogens*

Pathogen resistance differences between New Zealand *Mytilus* and *Perna* cannot be inferred as there is a paucity of usable data. Significant differences or otherwise would inform predictions as to the threat posed by overseas *Mytilus* parasites to New Zealand *Perna* and *vice versa*.

Recommendation

- Samples of *P. canaliculus* and *M. galloprovincialis* of similar age, size and location should be compared with a view to establishing whether any statistical difference in parasite load or pathology exists.

3.1.2. Invasive dynamics and possible development of pathological threat

The greatest potential threat to New Zealand *Perna canaliculus* aquaculture appears to be posed by parasites introduced by invading *Mytilus* species. These common ship-borne fouling organisms are a likely source of overseas pathogens, the most important of which are probably *Marteilia* spp. and disseminated haemic neoplasia - Bower & Figueras (1989) report *M. edulis* infected with *Marteilia refringens* and assert that these mussels might serve as reservoirs of infection. Hybridisation of invasive and local mussels presents a further potential pathology hazard by production of a more susceptible reservoir host suitable for these pathogens. Support for this is found in Beaumont *et al.* (2004) who report depressed performance of *M. edulis* x *M. galloprovincialis* hybrids when compared with pure species. In addition, Fuentes *et al.* (2002) report the lower viability of hybrids challenged by heat shock or infection with *Marteilia refringens*.

The physical coincidence of hybridising mussels and pathogens in New Zealand waters is likely: *Mytilus* species are arriving regularly in New Zealand and they could be carrying pathogens such as *Marteilia*. Arrival of *M. edulis* facilitates hybridisation of *M. edulis* x *M. galloprovincialis* and the resulting hybrid, because of its increased susceptibility to *Marteilia refringens,* might provide a more accommodating reservoir host with a consequent increase in numbers of pathogen transmission stages. This proliferation of transmission stages might be a cause of concern for *Perna canaliculus* whose susceptibility is currently unknown.

The specific pathogens are discussed below in 3.1.3. and 3.1.4.

3.1.3. Marteilia

The pathological threat to *Perna canaliculus* posed by *Marteilia* remains undetermined: is *Marteilia* not reported from *Perna canaliculus* because of resistance, or because of lack of exposure to *Marteilia?* If currently resistant to *Marteilia*, is this likely to be compromised by outbreeding depression in *Perna canaliculus* crosses of geographically disparate strains as a result of aquaculture activities?

3.1.4. Disseminated haemic neoplasia

Mytilus hybrids (Fuentes *et al.* 2002) appear to be more susceptible, and invasion dynamics are likely to produce hybrids contemporaneously with the arrival of the neoplasia. The potential thus exists for production of more infected susceptible hosts and greater water load of transmission stages. Such increase in transmission stages might be a cause of concern for *Perna canaliculus* whose susceptibility is unknown.

Recommendations – the following should be addressed

- What species of mussels are coming to New Zealand in ballast water *etc.*?
- Are there introduced species of *Mytilus* (other than *M. galloprovincialis*) in New Zealand harbours?
- Are they accompanied by indigenous *M. galloprovincialis?*
- Is there any evidence for *Mytilus* hybridisation?
- Are neoplasia or *Marteilia* present and, if so, does prevalence and intensity vary with host genetics?
- Is *Perna canaliculus* susceptible to these conditions?
- If these diseases are here, do they have higher prevalences in harbours and around areas of higher pollution stress?

3.2. The threat of New Zealand molluscan parasites to our export markets

Most of the recorded parasites and diseases in New Zealand mussels are also found in the local waters of our major customers overseas. With the exceptions of the pathogens discussed below, there appears to be no major pathological obstacle to production and marketing of the Greenshell™ mussel. Since ofshore aquaculture of mussels in New Zealand is likely to increase in future, local prospect are likely to be improved further if Buck *et al.* (2005) are correct in reporting that *M. edulis* collected from offshore culture sites had lower numbers of parasites and that these results can be extrapolated to *Perna canaliculus*.

3.2.1. Threats posed by New Zealand mussel parasites

Of the parasites reviewed, only *Enterogonia orbicularis*, APX and the digestive RNA virus in New Zealand mussels appear to pose a potential, but so far unquantified, threat should they be introduced to mussel populations overseas.

E. orbicularis is of minor significance in New Zealand, but consideration should be given to its destructive potential in overseas mussel populations.

Recommendations

- Assess susceptibility of *Mytilus galloprovincialis* to *E. orbicularis* infestation.
- Assessment should be made of current numbers occurring in export mussels (if any) and devise appropriate mitigation measures as necessary.

The digestive epithelial virus, or close relatives, appear also in scallops and clams in New Zealand, and other molluscs elsewhere such as in Australia, Scotland, and Denmark. Since infections have been associated with moderate to severe mortalities in some cases, appropriate measures are required when exporting our mussels to countries where this virus has not been reported.

Recommendations

- Assess susceptibility of *Mytilus galloprovincialis* to infection.
- Purification and sequencing of virus for identification and also for devising molecular detection methods such as PCR.
- Examination of genetic affinities of the various viruses of this type world-wide.
- Assess transmission and virulence in different hosts.

APX (Diggles *et al.* 2002; Hine 2002b) has been found in mussels from the Marlborough Sounds and could pose a potential threat to other mussels and oysters.

Recommendations

- Assess susceptibility of *Mytilus galloprovincialis* to infection.
- Survey local *Mytilus galloprovincialis* for APX.
- Assess transmissibility to mytilids and other bivalves.
- Assess pathology and virulence in range of hosts.
- Purification and sequencing of APX for identification and detection.

3.2.2. Threats posed by other New Zealand shellfish parasites to overseas shellfish

Herpes virosis and rickettsiosis are ubiquitous and no special precautions are needed other than routine monitoring. The New Zealand *Bonamia exitiosa,* mycoplasmosis and *Perkinsus olseni*

are of concern as they are either OIE listed or of unassessed pathological threat to non-New Zealand molluscs.

Recommendations

- Effort should be expended to exclude New Zealand molluscs harbouring these from shipments of Greenshell™ mussels.
- Ensure that New Zealand export molluscs are free (to OIE standards) of these diseases.
- Assess the threat of these diseases to recipient countries.

3.3. Other potential health hazards

The anisakid occurrence is not considered a significant human health threat as it was an isolated report and any significant levels would be detected during routine examination. Moreover, mussels are rarely eaten raw and cooking would obviate the danger. No specific recommendation is required as routine surveying will detect any rising trends. There is a possibility of mytilids acting as reservoirs for birnaviruses, especially in areas of culture in proximity with finfish.

Recommendation

- Surveying for these viruses should be performed where mussels are cultured in proximity to populations of susceptible finfish.

3.4. Management of perceived threats

Whether valid or not, overseas regulatory agencies can cite such pathogens as significant threats. They might then be used to argue for non-tariff trade barriers with the onus on New Zealand to refute them. Further work is thus required to gauge their true pathological potential to enable us to forestall any potential objections. This would include:

Recommendations

- Formulation of credible policies for managing the risk they pose to overseas customers.
- Knowledge of current acceptable import standards.

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