

Native and non-indigenous boring polychaetes in Chile: a threat to native and commercial mollusc species

Poliquetos perforadores nativos y no indígenas en Chile:
una amenaza para moluscos nativos y comerciales

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ABSTRACT

Boring polychaetes infesting the shells of aquacultured molluscs affect host fitness and cause serious economic problems for the aquaculture industry. In Chile, knowledge of the native and non-indigenous polychaete fauna associated with mollusc hosts is limited, in spite of the fact that numerous native and non-indigenous mollusc species are actively harvested. We present the first complete list of boring polychaete species present in Chile, with a review of the information regarding each species' status as a native or non-indigenous species (NIS), together with information on native and introduced ranges, affected host species, likely vectors of introduction and donor areas. We recorded a total of nine boring polychaetes present along the Chilean coast including native and NIS. Within the NIS category we provide the first published report of the Sabellid *Terebrasabella heterouncinata* in South America. Boring polychaetes utilized both native and introduced host species. The finding of polychaete species which utilized multiple native and NIS hosts, indicates a potential risk for spread between aquaculture facilities and the natural environment. Our analysis suggests that aquaculture activities are probably the primary introduction vector for boring polychaete species to Chile and that this region does not differ in the magnitude of introduced boring polychaetes relative to other regions of the world. We discuss current laws and management regarding polychaete infestations and make recommendations for future management in Chile, which should contemplate a rational compromise between the socio-economic needs of the country and plans to protect and preserve the nation's biodiversity.

Key words: Bioinvasions, legislation, management, NIS, Southeastern Pacific.

RESUMEN

La colonización de especies de poliquetos perforadores sobre conchas de moluscos de cultivos puede afectar la adecuación biológica del hospedador y causar serios problemas económicos para la industria acuícola. En Chile, el conocimiento de la fauna de poliquetos perforadores nativos y no indígenas asociados con moluscos hospedadores es limitado, a pesar del gran número de moluscos nativos y no indígenas que son activamente cultivados. Se presenta el primer listado completo de poliquetos perforadores en Chile, con información sobre el estatus de cada especie como nativa o especie no indígena (ENI), rangos nativos e introducidos, las especies hospedadores afectadas, los probables vectores de introducción y áreas donantes. Se registró un total de nueve especies de poliquetos perforadores en Chile, incluyendo especies nativas y ENI. Dentro de la categoría ENI se registra por primera vez a *Terebrasabella heterouncinata* en Sudamérica. Los poliquetos perforadores infestan especies nativas e introducidas. El hallazgo de poliquetos que utilizan múltiples hospedadores nativos y ENI, indica un potencial riesgo de diseminación entre centros de cultivos y el ambiente natural. Nuestro análisis sugiere que las actividades acuícolas son probablemente el principal vector de introducción de especies de poliquetos perforadores en Chile, no difiriendo en orden de magnitud con respecto a otras regiones del mundo. Se discute la actual legislación y planes de manejo sobre infestaciones de poliquetos perforadores y se realizan recomendaciones para el futuro manejo en Chile, la que debería contemplar un compromiso racional entre las necesidades socioeconómicas del país y planes de protección y preservación de la biodiversidad de la nación.

Palabras clave: Bioinvasiones, legislación, manejo, ENI, Pacífico suroriental.

INTRODUCTION

Aquacultured organisms are frequently fouled by a diverse array of epibionts, including algae, sponges, bryozoans, barnacles, molluscs, ascidians and polychaetes (e.g. Corriero & Pronzato 1987, Martin & Britayev 1998, López et al. 2000, Giacobbe 2002, Castilla et al. 2005). When marine species are introduced to new areas—often for aquaculture purposes—their associated epibionts can also be accidentally introduced (Naylor et al. 2001). This phenomenon presents a risk to the biodiversity of the recipient communities through species interactions between the non-indigenous assemblage and the recipient community (e.g. Naylor et al. 2001). For example, the non-indigenous epibionts may acquire new hosts in the recipient communities (e.g. Kuris and Culver 1999, Culver & Kuris 2004) or, conversely, organisms from the recipient community may learn to consume or otherwise utilize the introduced species (e.g. Magoulick & Lewis 2002). Either of these scenarios could lead to changes in population dynamics and community structure (e.g. Grosholz et al. 2000, Ross et al. 2003).

Boring polychaetes frequently infest the shells of aquacultured mollusc species. These polychaetes can cause severe damage to the mollusc shells, affecting the fitness of their hosts (Blake & Evans 1973, Handley & Berquist 1997, Cáceres-Martínez et al. 1998, Martin & Britayev 1998, Read 2004, McDiarmid et al. 2004) and often causing financial loss to aquaculturists. At least three families of boring polychaetes have been reported in the literature: Spionidae, Sabellidae and Cirratulidae. In particular, boring polychaetes of the spionid genera such as *Boccardia*, *Dipolydora*, *Polydora* and the sabellid *Terebrasabella heterouncinata* Fitzhugh and Rouse cause serious economic problems for the aquaculture industry at a global level (see Evans 1969, Kuris & Culver 1999, Leonart et al. 2003a, 2003b, Cárdenas & Cañete 2004, Read 2004, Radashevsky & Olivares 2005). The specific effects of boring polychaete species on their hosts have been well-studied for several commercially important molluscs both in their native and introduced ranges (e.g. oysters, scallops, mussels, abalone; Kent 1979, Basilio et al. 1995, Cáceres-Martínez et al. 1998, Kuris &

Culver 1999, McDiarmid et al. 2004, Vargas et al. 2005), however there are few available studies of boring polychaetes on species that are not of economic importance.

In Chile, information regarding infestations of native and non-indigenous boring polychaetes on native and exotic molluscs of commercial importance is available, particularly for Spionidae polychaetes (see Rozbaczylo et al. 1980, Rozbaczylo et al. 1994, Basilio et al. 1995, Sato-Okoshi & Takatsuka 2001, Cárdenas & Cañete 2004, Radashevsky & Olivares 2005, Bertrán et al. 2005) and Cirratulidae polychaetes of the genus *Dodecaceria* (see Carrasco 1977, Rozbaczylo & Carrasco 1996). Nevertheless, Chile continues to lag behind other countries (e.g. Australia, New Zealand, USA) in the development of plans to prevent and manage polychaete invasions both to aquaculture facilities and natural environments. As Chile becomes an important global provider of several non-indigenous aquaculture products (e.g. salmon, abalone) it is vital to begin risk assessment and to implement appropriate management strategies to protect natural ecosystems while continuing to look after the socioeconomic interests of the country.

The purpose of this work is twofold: (1) to provide the most current listing of marine boring polychaete species present in Chile, reviewing information regarding each species' status as a native or non-indigenous species, together with information on native and introduced ranges, affected host species, and likely vectors of introduction and donor areas and (2) to discuss current laws and management regarding polychaete infestations and make recommendations for future management in Chile.

Database and selection criteria

The database compiled for this study consists in an exhaustive bibliographic review of boring polychaete species on calcareous substrates recorded along the Chilean coast, from the northern geopolitical boundary in Arica (18°20' S) to the southern tip of the continent at Cape Horn (56° S). We reviewed the list of polychaetes of Chile compiled by Rozbaczylo (1985; and posterior publications) and technical reports from aquaculture facilities; in addition

we conducted personal interviews with marine biologists, and experts in aquaculture and biosecurity from governmental and private entities¹ (see Appendices I and II). Using these sources we compiled a list of all of the boring polychaete species recorded in Chile. We categorized each of the selected species according to its geographic distribution as: (1) *Native species* (i.e. species with an historic range of distribution in Chile or Peru² and (2) *Non-indigenous species (NIS)*; i.e. species with a recent record in Chile, present outside of their native or historic range of distribution or their natural range of dispersal³; such species typically present a notorious, biogeographically incongruous range of distribution). For a marine boring polychaete to be included in the NIS category it had to conform to at least one of the following operational criteria based on Orensanz et al. (2002) and Castilla et al. (2005): (1) species whose non-native status in Chile was well-documented in scientific publications, written governmental reports, and/or based on the professional experience of the authors; (2) species with a notorious, incongruent range of distribution, including a single report or discontinuous range within Chile, (3) species with an extremely wide geographical distribution, including cosmopolitan species, (4) species documented as NIS in other regions, (5) species that were abundant in the vicinity of presumed centers of introductions (e.g. ports, aquaculture facilities), but rare or absent from other studied areas.

¹ Given current controversy regarding legislation restricting aquaculture activities we are not able to provide the names of the experts that we interviewed in our published work. Instead we have provided the name of the researcher who conducted the interview. Additional information regarding specific interview questions and the professional profile of the experts we interviewed are available in Appendices I and II.

² We included the coast of Peru in our definition so as not to increase the number of NIS on the list by adhering to strict political boundaries. Therefore, if a species has an historic range in Peru as well as reports in Chile we have reported it as native to Chile. Note that using this broader geographic range may result in the inclusion of species that have undergone southward range extensions to Chile (such as those associated with ENSO phenomena).

³ For this database we considered NIS to be those boring polychaete species present beyond the southeastern Pacific coasts of Chile or Peru, with a "recent" record in Chile; there was generally additional evidence of the non-native status of such species, such as a lack of records in the early literature or reported association with an introduced aquaculture species.

In Appendix III we provide a detailed identification of the three new records of boring polychaetes species recorded in this study. The identification of these species was made following keys by Gravier (1908), Fauchald (1977), Rozbaczylo (1980) and Fitzhugh & Rouse (1999). We used a stereomicroscope and a scanning microscope to examine the diagnostic characters for each species. In addition, we compiled a list of the host species in Chile affected by each of the boring polychaete species in the database, with information on the status of each host as Native or Non-Indigenous to the Chilean coast and whether or not the host species is of economic importance. Finally, for each of the non-indigenous polychaete species we compiled information on their native and introduced ranges, and utilized this information, together with data on affected host species, to propose potential vectors and pathways of introduction to Chile. While precise introduction vectors and pathways are not known with certainty, we utilize indirect evidence (i.e. published reports of pathways used by congeneric or biologically similar species introduced to other marine systems around the world) or direct evidence of the presence of marine NIS utilizing specific vectors in Chile (e.g. specimens present on the shells of introduced mollusc species) following Castilla and Neill (in press).

MARINE BORING POLYCHAETES IN CHILE

Current knowledge of boring polychaetes in Chile

This is the first complete review of native and non-indigenous boring polychaetes present on the southeastern Pacific coast of Chile, together with information on the affected hosts and the possible vectors and donor areas of NIS polychaetes to the Chilean coast. We recorded a total of nine boring polychaete species present along the Chilean coast, belonging to the families Spionidae, Cirratulidae and Sabellidae. Three of these species were classified as native species (Table 1) and six species were classified as NIS (Tables 1 and 2). The geographical distributions of boring polychaete species recorded on the Chilean coast are presented in Table 3. Within the NIS

category we emphasize the first published report of the sabellid fan worm, *Terebrasabella heterouncinata* in South America, which corresponds to specimens found infesting *Haliotis rufescens* in an abalone aquaculture facility of southern Chile (R.A. Moreno, personal interview).

Chile exhibits the same order of magnitude of introduced boring polychaetes relative to other regions of the world: 12 NIS polychaetes in New Zealand (see Cranfield et al. 1998, Handley 2000, Read 2004); seven in California, USA (see Blake and Evans 1973, Boyd et al. 2002); and seven in Australia (see McEnulty

TABLE 1

List of boring polychaete taxa recorded on the Chilean coast, with information on the status of each polychaete as Native or Non-Indigenous species (NIS). In addition we list the host species that are affected by each boring polychaete, and we indicate whether affected hosts are Native or Non-Indigenous species in Chile, and whether the host is of direct economic importance (\$)

Lista de taxa de poliquetos perforadores registrados en la costa del Pacífico suroriental de Chile, con información sobre el estatus de cada especie de poliqueto como Nativo o No indígena. Además se incluye una lista de las especies hospedadoras afectadas por cada poliqueto perforador, y se indica el estatus de los hospedadores como especies Nativas o No indígenas en Chile, y su importancia económica (\$)

Boring polychaete species	Polychaete status	Affected host species	Host status	Source
<i>Dipolydora huelma</i> Sato-Okoshi & Takatsuka, 2001	Native	<i>Crepidula</i> sp.	Native	1
		<i>Haliotis rufescens</i>	NIS, \$	2
<i>Dodecaceria choromyticola</i> Carrasco, 1977	Native	<i>Choromytilus chorus</i>	Native*, \$	3
		<i>Fissurella maxima</i>	Native, \$	4
		<i>Aulacomya ater</i>	Native, \$	4
		<i>Austromegabalanus psittacus</i>	Native, \$	5
<i>Dodecaceria</i> cf. <i>opulens</i> Gravier, 1908	Native	<i>Concholepas concholepas</i>	Native, \$	4
		<i>Haliotis rufescens</i>	NIS, \$	This study
		<i>Balanus flosculus</i>	Native	6
		<i>Jhelius cirratus</i>	Native	6
<i>Boccardia tricuspa</i> (Hartman, 1939)	NIS	<i>Perumytilus purpuratus</i>	Native	6
		<i>Austromegabalanus psittacus</i>	Native, \$	5
		<i>Lithothamnion</i> sp.	Native	1
		<i>Crepidula</i> sp.	Native	1
		<i>Argopecten purpuratus</i>	Native*, \$	1
		<i>Ostrea chilensis</i>	Native, \$	1
<i>Dipolydora giardi</i> (Mesnil, 1896)	NIS	<i>Crassostrea gigas</i>	NIS, \$	1
		<i>Mesodesma donacium</i>	Native, \$	7,8
		<i>Mulinia edulis</i>	Native, \$	This study
		<i>Crepidula fecunda</i>	Native	9
<i>Polydora biocipitalis</i> Blake & Woodwick, 1971	NIS	<i>Crepidula</i> sp.	Native	1
		<i>Fissurella nigra</i>	Native, \$	1
		<i>Argopecten purpuratus</i>	Native*, \$	1, 10
		<i>Ostrea chilensis</i>	Native, \$	1
<i>Polydora rickettsi</i> Woodwick, 1961	NIS	<i>Crassostrea gigas</i>	NIS, \$	1
		<i>Haliotis rufescens</i>	NIS, \$	2
		<i>Haliotis discus hannai</i>	NIS, \$	11
<i>Polydora uncinata</i> Sato-Okoshi, 1998	NIS			
<i>Terebrasabella heterouncinata</i> Fitzhugh & Rouse, 1999	NIS	<i>Haliotis rufescens</i>	NIS, \$	12, this study

1: Sato-Okoshi & Takatsuka (2001); 2: Vargas et al. (2005); 3: Carrasco (1977); 4: Rozbaczylo & Carrasco (1996); 5: Hernández et al. (2001); 6: Rozbaczylo et al. (1994); 7: Blake (1983); 8: Rozbaczylo et al. (1980); 9: Bertrán et al. (2005); 10: Basilio et al. (1995); 11: Radashevsky & Olivares (2005); 12: Kuris & Culver (1999)

* This species is considered to be "native to Chile", however within the country it has been trasplanted to culture facilities located outside of the native range

et al. 2001, Hayes et al. 2005). Members of the family Spionidae were the most frequent boring polychaete species observed in Chile (one native and five introduced species). This finding coincides with reports from other aquaculture centers on the Pacific coast where Spionidae are the most frequently reported boring polychaete species (e.g. Eastern Pacific coast: USA, Baja California, México; Blake & Evans 1973, Cáceres-Martínez & Tinoco-Orta 2001, northwestern Pacific coast: Japan; Sato-Okoshi 1999; and the southwestern Pacific coast: Australia; Leonart et al. 2003a, 2003b, McDiarmid et al. 2004).

In Chile only three of the Spionidae species (*Dipolydora huelma*, *Polydora rickettsi* and *P. uncinata*) have been studied in terms of their effects on economically important introduced mollusc species (e.g. *Haliotis* spp.). All of these polychaetes have been found in land-based abalone aquaculture facilities. In southern Chile *D. huelma* and *P. rickettsi* are reported to infest *Haliotis rufescens* abalone farms. Infestation prevalence varies considerably according to the polychaete species (i.e. *D. huelma* has been reported to infest over 88 % of mature abalone, while *P. rickettsi* infested approximately 24 % of mature abalone), whether specimens are immature or mature (i.e. mature specimens are more infested) and locality (Vargas et al. 2005). In northern Chile *P. uncinata* had notably high levels of infestation prevalence, being found on up to 98.8 % of medium to large sized *Haliotis discus hannai* (Radashvsky & Olivares 2005). While these high prevalences of boring polychaetes in aquaculture facilities suggest important consequences for aquaculturists, none of these studies report on economic loss associated with polychaete infestations.

The two other families of boring polychaetes found in Chile were represented by fewer species (two species belonging to Cirratulidae and one species of Sabellidae). The two Cirratulidae species (*Dodecaceria choromyticola* and *D. cf. opulens*) were found infesting native and exotic hosts of economic importance on the Chilean coast. However, the economic effects of the infestation by *Dodecaceria* in culture centers on the Chilean coast are largely unknown, which is of concern especially considering that *Dodecaceria* is a reported pest in scallop cultures (*Placopecten*

magellanicus) in New England (Blake 1969, Martin & Britayev 1998). Furthermore, the discovery of one Sabellidae species (*Terebrasabella heterouncinata*) infesting red abalone (*Haliotis rufescens*) in Puerto Montt, southern Chile (Table 2) represents the first published record of this species in South America (R.A. Moreno, personal interview). This species has been widely documented as a marine pest in abalone culture centers in California, USA, where numerous studies have been conducted in attempts to control and/or eradicate this pest (Culver et al. 1997, Kuris & Culver 1999, Culver & Kuris 2000). Given the magnitude of damage caused by *T. heterouncinata* in aquaculture facilities on the northeastern Pacific coast, this polychaete constitutes a serious threat for aquaculture activities on the Chilean coast. At present this polychaete has only been observed in a closed circuit land-based culture system and all known hosts containing specimens were placed in quarantine and later eliminated (R.A. Moreno, personal interview).

Affected host species

The boring polychaete species utilized a total of 19 different host species, consisting in 15 mollusc species, three crustaceans and one calcareous encrusting alga. This listing included six native hosts with no commercial value, 10 native hosts with commercial value, and three NIS hosts introduced for aquaculture purposes (Table 1). We found evidence of native boring polychaete species infesting both native and non-indigenous hosts, as well as the contrary case of non-indigenous polychaetes infesting native and non-indigenous hosts. Three of the polychaete species presented host specificity: the non-indigenous polychaetes *Polydora uncinata* and *Terebrasabella heterouncinata* bored into introduced aquaculture species (i.e. *Haliotis* spp.), while the native *Dodecaceria choromyticola* infested economically important native molluscs. At present the two non-indigenous polychaetes are reported to present high host-specificity (*Polydora uncinata* and *Terebrasabella heterouncinata*), and are found only in land-based abalone aquaculture systems. Currently there is no available information regarding the potential introduction of this species to the

TABLE 2

Listing of non-indigenous boring polychaete species in Chile according to likely introduction pathway(s), native range, and introduced range. Abbreviations are: NATL (North Atlantic), SATL (South Atlantic), NPAC (North Pacific), CPAC (Central Pacific), and SPAC (South Pacific)

Listado de especies de poliquetos perforadores no indígenas en Chile según probables vías de introducción, rangos nativos y rangos introducidos. Abreviaciones son: NATL (Atlántico Norte), SATL (Atlántico Sur), NPAC (Pacífico Norte), CPAC (Pacífico Central), y SPAC (Pacífico Sur)

NIS boring polychaete species	Potential introduction pathway(s)	Native range	Introduced range	Introduced range in Chile	Source
<i>Dipolydora giardi</i>	Introduced with Cultured Host Species (i.e., <i>Crassostrea gigas</i>)	MANY (Cosmopolitan) NATL: Europe; France, United Kingdom, Ireland, S North Sea NPAC: Van-couver, Japan CPAC: Ecuador, Galapagos Islands	NPAC: USA (California), Mexico SPAC: Chile	Montemar (32°58'S), Pullinque, Hueihue, Huelmo (41°40'S), Juan Fernández Archipelago (33°40'S)	1, 2, 3
<i>Boccardia tricuspa</i>	Unclear	NPAC: USA (California), Mexico CPAC: Ecuador, Galapagos Islands	SPAC: Chile	Las Cruces (33°31'S), Concepcion Bay (36°30'S), San Vicente Bay (36°45'S), Puerto Montt (41°30'S)	3, 4, 5
<i>Polydora biocipitalis</i>	Unclear	NPAC: USA (California) NATL: Europe; France, United Kingdom, Ireland, S North Sea NPAC: Mexico	SPAC: Chile Australia (New South Wales, Victoria), New Zealand, Chile	Arica, Playa El Águila (20°54'S), Playa Morillos (30°09'S), El Tabo (33°27'S)	2, 6
<i>Polydora rickettsi</i>	Introduced with first cultures of host species (i.e., <i>Crassostrea gigas</i> , which was introduced in 1977; Servicio Nacional de Pesca 1999; but see Basilio et al. 1995 indicating presence in <i>Argopecten purpuratus</i> prior to <i>Crassostrea gigas</i> at one site), also associated with the culture of <i>Haliothis</i> spp., introduced to Chile in 1981	NPAC: Mexico	SPAC: Chile	Caldera (27°04'S), Tongoy Bay (30°14'S), Montemar, Concepción Bay (36°30'S), Quillaipe, Pullinque, Hueihue, Castro (42°29'S), Yaldad Bay (43°07'S), Chiloé Island (43°00'S)	3, 7, 8, 9
<i>Polydora uncinata</i>	Introduced with Cultured Host Species (i.e., <i>Haliothis</i> spp.)	NPAC: Japan	SPAC: Chile	Coquimbo (29°55'S)	10, 11
<i>Terebrasabella heterouncinata</i>	Introduced with Cultured Host Species (i.e., <i>Haliothis</i> spp.)	SATL: South Africa	NPAC: California, Mexico SPAC: Chile	Puerto Montt (41°30'S)	12, 13, this study

1: Blake & Kudenov (1978); 2: Blake (1983); 3: Sato-Okoshi & Takatsuka (2001); 4: Carrasco (1977); 5: Rozbaeczylo et al. (1994); 6: Rozbaeczylo et al. (1980); 7: Basilio et al. (1995); 8: Bertrán et al. (2005); 9: Vargas et al. (2005); 10: Sato-Okoshi (1998); 11: Radashkevsky & Olivares (2005); 12: Kuris & Culver (1999); 13: Culver & Kuris (2000)

natural environment from the land-based systems (e.g. escape via effluent tubes). Furthermore, recent Chilean legislation now allows for the abalone hosts of these two species to be cultivated in open and semi-enclosed circuits in nearshore waters on the northern and southern coasts of Chile (FONDEF 1999, 2001, 2003, PYME 2005, see also discussion), which could constitute a potential risk to native host populations (Naylor et al. 2001). The other six species were observed to utilize multiple host species (Table 1). The finding that some native polychaetes also utilize introduced aquaculture species is cause for concern, since the high densities of available NIS hosts could support higher abundances of boring polychaete populations, which could subsequently increase the load of polychaetes on their native hosts. Likewise, the finding that several non-indigenous polychaetes utilize multiple hosts (including both native and introduced hosts) also constitutes a serious threat to native organisms which are affected by this load of new 'parasites' lacking a common evolutionary history (Sax & Brown 2000).

Vectors and pathways of boring polychaete introductions to Chile

Aquaculture activities are likely the primary vector of introduction of exotic boring polychaetes to Chile (Table 2), probably involving long-distance transfers of polychaetes on molluscs from aquaculture facilities on other continents. This hypothesis is supported by the observations that four polychaete NIS are present in aquaculture centers and are reported to infest at least one exotic host species in Chile (Tables 1 and 2). For at least two polychaete species the data suggest that following their introduction with aquacultured species (e.g. *Crassostrea gigas*, *Haliotis* spp.) the polychaete taxa were able to disperse locally to nearby populations of native host species. These native hosts may promote further dispersal of the introduced polychaetes within the natural environment.

We identified a variety of possible donor areas, including the North Pacific Ocean (both east and west coasts), the Central Pacific (east coast), the South Pacific (east coast and west coast), the North Atlantic (east coast) and the

TABLE 3

Global geographical distribution of boring polychaete species recorded on the Chilean coast

Distribución geográfica global de las especies de poliquetos perforadores registrados en la costa de Chile

Boring polychaete species	Geographical distribution
<i>Boccardia tricuspa</i> (Hartman, 1939)	California, east coast of Mexico, Ecuador, Galapagos Islands (Hartman 1968, Blake 1983); Chile: Las Cruces (Rozbaczylo et al. 1994) to Puerto Montt (Sato-Okoshi & Takatsuka 2001)
<i>Dipolydora giardi</i> (Mesnil, 1896)	Cosmopolitan on calcareous substrates (Sato-Okoshi & Takatsuka 2001); Ecuador (Blake 1983); Chile: Montemar; Puerto Montt (Sato-Okoshi & Takatsuka 2001), Juan Fernández Archipelago, Robinson Crusoe Island (Blake 1983)
<i>Dipolydora huelma</i> Sato-Okoshi & Takatsuka, 2001	Chile: Seno Reloncaví (Sato-Okoshi & Takatsuka 2001); Puerto Montt, Castro-Chiloé (Vargas et al. 2005)
<i>Dodecaceria choromytica</i> Carrasco, 1977	Chile: Coliumo Bay (Carrasco 1977)
<i>Dodecaceria</i> cf. <i>opulens</i> Gravier, 1908	Perú; Chile: Península Hualpén, Concepción (Hernández et al. 2001); Puerto Montt
<i>Polydora biocippitalis</i> Blake & Woodwick, 1971	California; Chile: El Águila, a beach south of Iquique (Blake 1983); Santo Domingo, a beach south of the Port of San Antonio
<i>Polydora rickettsi</i> Woodwick, 1961	Baja California, Mexico (Woodwick 1961); Chile: from Tongoy Bay (Basilio et al. 1995) to Chiloé (Vargas et al. 2005)
<i>Polydora uncinata</i> Sato-Okoshi, 1998	Japan (Sato-Okoshi 1998); Chile: Coquimbo (Radashvsky & Olivares 2005)
<i>Terebrasabella heterouncinata</i> Fitzhugh & Rouse, 1999	South Africa; California, Baja California, Mexico (Kuris & Culver 1999); Chile: Puerto Montt

South Atlantic (east coast). Five of the six NIS likely arrived from the northern hemisphere (Table 2). On the southeastern Pacific coast of Chile there was no clear pattern regarding areas of introduction. Non-indigenous polychaete species were observed in at least 20 different sites in northern, central and southern Chile, ranging from Arica (20° 54' S) to Yaldad Bay (43° 07' S) (Table 2). The NIS polychaetes, *P. uncinata* and *T. heterouncinata* were recorded only in land-based aquaculture systems, while the native *D. huelma* was recorded in both land-based aquaculture systems and natural environments. The native *Dodecaceria choromyticola* was observed only in sea-based aquaculture systems and the NIS polychaetes *D. giardi*, and *P. rickettsi* were observed in both sea-based aquaculture systems and natural environments. Finally, two of the NIS, *B. tricuspa* and *P. bioccpitalis*, were recorded only in natural environments in the intertidal and shallow subtidal zones of the Chilean coast. The lack of a clear pattern in the introduced ranges of polychaete NIS within Chile may be a product of incomplete information regarding boring polychaete infestations on native hosts that are not of economic importance. Nevertheless, it is important to highlight that secondary pathways of dispersal from the source site may exist (e.g. the transfer of boring polychaetes on shellfish or aquaculture equipment moved between facilities). Evaluating potential vectors and introduction pathways of boring polychaetes is a fundamental part of the risk assessment process (e.g. Ruiz & Carlton 2003).

CURRENT LAWS AND MANAGEMENT AND RECOMMENDATIONS FOR FUTURE MANAGEMENT

Legislation and management of boring polychaetes in Chile

It is important to highlight that although Chile has legislation regarding exotic species introductions to marine environments (The Fishery and Aquaculture Law, "Ley General de Pesca y Acuicultura" 1989), the main emphasis of these regulations has been on protecting the nation's natural resources. While written environmental law (Law 18.892) stipulates that aquaculturists must assure conditions that

guarantee the protection of "biodiversity" (PYME 2005), in practice law-enforcers only effectively monitor effects on the "biodiversity" of native species of economic importance (e.g. *Concholepas concholepas*, *Fissurella* spp.).

Current legislation is focused on preventing the introduction and dispersal of non-target marine species associated with aquaculture activities (The Fishery and Aquaculture Law, "Ley General de Pesca y Acuicultura" 1989). For example, together with approving and financing projects to cultivate exotic abalone (*Haliotis* spp.) in sea cages along the Chilean coast, the government has also passed legislation which specifies that the abalone can only be farmed in areas devoid of hard substrates, and that concessions must strictly adhere to programs of environmental vigilance regarding the protection, control and eradication of "diseases" that present significant risks to hydrobiological species (Resolutions N° 319/01 and 320/01 of Ministerio de Economía, Fomento y Reconstrucción, hereafter MEFR). However, many aquaculturists remain doubtful regarding whether it is possible to find adequate areas for aquaculture which comply with all of the measures of protection (e.g. areas devoid of hard substrates) (P.E. Neill, personal interview).

In addition, the government has provided funding to an institution (i.e. Fundación Chile) in charge of developing techniques for the prevention and control of infectious and non-infectious diseases in abalone, with specific reference to boring polychaetes (FONDEF 2001). Measures of polychaete prevention and control include quarantine of infested abalone, eradication of polychaetes via dessication, exposure to freshwater, chemicals or wax (R.A. Moreno, personal interview).

In 2003 the National Fisheries Service (Servicio Nacional de Pesca, hereafter SERNAPESCA) established the Active Vigilance Program ("Programa de Vigilancia Activa", Resolution N° 1809/03) to monitor abalone and oyster aquaculture centers in Chile for high risk diseases. This monitoring program can also be extended to other aquaculture facilities and natural populations of economically important mollusc species if solicited. This program consists in semi-annual monitoring (fall and spring-summer) in and near aquaculture centers for the presence of

specific high risk “diseases” in mollusc species. The monitoring is conducted by government authorized (SERNAPESCA) diagnostic laboratories who aim to identify sanitary risks associated with the aquacultured species as specified by a government ministry (i.e. MEFR), which dictates legislation on the Protection, Control and Eradication of High Risk Diseases to Hydrobiological Species (Resolution N° 319/01). A subgroup of this ministry (Subsecretaria de Pesca) emits two lists of high risk disease organisms which should be evaluated (for more details see the Aquatic Animal Health Code, OIE 2005). Nevertheless, under current sanitary legislation (Resolution N° 1623/05 MEFR), many polychaetes and other epi- or endo-bionts which are known to be present in aquaculture facilities are not considered “disease” agents, in spite of the damage that they cause to economically important mollusc species (e.g. “polydoriasis”, Lleonart et al. 2003a, 2003b). At present SERNAPESCA is working to improve regulations to include the control of organisms that damage aquaculture facilities, but which have not yet been included on the high risk diseases lists (R.A. Moreno, personal interview).

The Chilean government has expressed its commitment to protecting native biodiversity by signing several international agreements (Camus 2005), including the International Convention on the Trade of Threatened Species of Wild Fauna and Flora (CITES, Supreme Decree N° 141/75), which makes references to preventing the introduction of non-indigenous species that threaten ecosystems, habitats or species, and controlling or eradicating NIS which have been introduced. While in theory Chilean legislation aims to protect aquatic resources against unwanted invaders, such as non-indigenous boring polychaetes, whether or not these regulations are enforced or even feasible remains to be seen. The current socio-economic concerns of the country place strong pressure on law makers and enforcers which may hinder the application of measures to protect biodiversity in the field. For example, aquaculturists are currently lobbying to assuage proposed legislation to permit abalone farming in more marine areas (P.E. Neill, personal interview).

Worms settling onto and boring into shells cause myriad problems for aquaculturists (e.g.

spoiled shell shape and quality, internal shell blisters, serious reduction in shell strength, damaged adductor muscles, energy wasted on shell repair, reduced flesh condition and increased vulnerability to serious pathogens, massive mortalities and resulting economic loss; Dunphy and Wells 2001, Lleonart et al. 2003a, 2003b, McDiarmid et al. 2004, Read 2004, Simon et al. 2004). Therefore, legislation to prevent, control and/or eradicate NIS polychaetes should provide long-term mutual benefits to both the nation’s economy (e.g. aquaculture) as well as to the nation’s native biodiversity. Nevertheless, social aspects of aquaculture in Chile, such as the need to obtain short-term profits-especially for small-scale aquaculturists-make the effective implementation of legislation and subsequent compliance with regulations a complex issue.

Future recommendations

Given the geographic layout of Chile (possessing over 4,200 km of coastline over 38 degrees of latitude, Camus 2001) this country has been touted as an ideal region for marine aquaculture; the same attribute, however, makes this region a prime target for non-indigenous species introductions. Given that exotic species introductions is a topic of global concern, and the fact that at least 6 NIS boring polychaete species are present on the Chilean coast, interacting with at least 14 native and non-indigenous hosts, it is important for researchers, managers and aquaculturists to develop strategies to prevent future introductions and to control or eradicate NIS that have already been introduced. Researchers need to generate baseline studies regarding the presence/absence of boring polychaetes in natural environments as well as determine the prevalence and ecological effects of non-indigenous polychaetes on their hosts.

A difficult task which must be broached in Chile is the need to develop a long-term plan which represents a rational compromise between the socio-economic plans for the country and plans to protect and preserve the nation’s biodiversity (Arroyo 2003, Camus 2005). To ensure marine biosecurity in Chile it is fundamental to implement preventive measures, including periodic monitoring of native populations in the vicinity of both land-

based and sea-based aquaculture facilities to detect and control the possible escape of non-target species, implementation of treatment systems for water discharged from aquaculture facilities into the ocean (e.g. mechanical methods, electrochemical treatments, UV radiation, chlorine treatment) development of certification protocols to assess the cleanliness of introduced aquaculture species and aquaculture equipment and the establishment of active vigilance programs to assure that infested organisms and equipment are not moved between facilities within the country (see Campalans 2005). Researchers should develop a document for aquaculturists and the general public, which educates about the risks of non-indigenous species introductions and provides an efficient plan-of-action to follow whenever an NIS is discovered. In addition to penalties for organizations that do not comply with laws regarding species introductions, proactive legislation should also be implemented to restrict the arrival of NIS to Chile. Specific areas of focus should be identifying and controlling vectors of introduction and primary donor areas, and being alert to the arrival of species that are reported as pests in other regions of the world.

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APPENDIX 1

Questions asked during interviews of professional specialists in marine biosecurity in Chile with respect to legislation and the management of pests and high risk infectious diseases provoked by boring polychaetes in aquacultured species

Preguntas realizadas a profesionales especialistas en bioseguridad marina en Chile, en relación a legislación y el manejo de plagas y enfermedades infecciosas de alto riesgo provocadas por poliquetos perforadores en especies de cultivos

- How does Chile rank among developed countries such as Australia, New Zealand and the USA in terms of preventative measures regarding marine biosecurity?
- Are the governmental institutions that are in charge of legislating marine biosecurity issues, such as the National Fisheries Service (Servicio Nacional de Pesca; SERNAPESCA) and the Subsecretary of Fisheries (Subsecretaría de Pesca; SUBPESCA), currently working to develop and/or perfect new regulations such as the control and management of pests that cause economic damage to aquaculture businesses? What kind of monitoring programs are currently in existence?
- Are private aquaculture businesses along the Chilean coast developing plans to lobby the current legislation allowing an increase in the number of aquaculture centres for species of economic importance? Which particular issues are currently of concern to aquaculturists?
- Are the governmental entities in charge of protecting, controlling and eradicating high risk infectious diseases in aquaculture currently creating documentation and/or a plan of action to incorporate polydioriasis as a high risk disease in Chile?
- Do the specimens of red abalone (*Haliotis rufescens*) that were infested with the boring polychaete *Terebrasabella heterouncinata* come from reproductive stocks imported from aquaculture centers in California, USA?
- What sanitary procedure was followed for specimens of *Haliotis rufescens* infested with *T. heterouncinata*?
- Were the specimens of *Haliotis rufescens* infested with *T. heterouncinata* located in a closed, land-based culture system on in the sea?

APPENDIX 2

Profile of the professionals who were interviewed during our study. We indicate the professional title and/or academic degree, institutional affiliation and area of speciality regarding marine biosecurity in Chile

Perfil profesional de los encuestados donde se indica el título profesional y/o grado académico, afiliación institucional y áreas de especialización en materias de bioseguridad marina en Chile

Academic degree	Institution	Function
Ph.D. in Biology	Subsecretary of Fisheries (SUBPESCA)	Biosecurity, laws
Veterinarian	National Fisheries Service (SERNAPESCA)	Pest management in aquaculture
Marine Biologist	Aqua-Gestión Fundación Chile	Pest management in aquaculture
Aquaculture Engineer	Private aquaculture business	Pest management in aquaculture

APPENDIX 3

Diagnosis of boring polychaete species recorded in this study infesting native and introduced mollusc hosts of economic importance on the Chilean coast

Diagnosis de las especies de poliuetos perforadores registradas en este estudio hospedando en moluscos nativos e introducidos de importancia económica en la costa de Chile

Terebrasabella heterouncinata Fitzhugh & Rouse, 1999

Diagnosis: we examined the external morphology of a total of seven specimens, which were obtained by decalcifying shells of the red abalone, *Haliotis rufescens* Swainson, from Puerto Montt, Chile (Fig. 1). The presence of a skeleton in the branchial crown, fusion of the mid-dorsal margins of the branchial lobes and the presence of companion setae on the thoracic neuropodia indicate that the specimens belong to the subfamily Sabellinae (according to Fitzhugh & Rouse 1999), within the family Sabellidae (according to keys by Fauchald 1977 and Rozbaczylo 1980). From the consistency in the observed characteristics for the seven specimens and the description by Fitzhugh & Rouse (1999), we were able to identify all of the specimens as belonging to the species *Terebrasabella heterouncinata*. The specimens were 1-1.5 mm long. The branchial crown had two pairs of radioles. The anterior half of the body was thinner, and the posterior half was slightly expanded and sac-like (Fig. 2). Each individual had 8 thoracic segments and only three abdominal segments. Thoracic neuropodial uncini present in setigers 2-8 were of two types: those in setigers 2-6 were acicular, with a distinct main fang surmounted by a series of smaller teeth, while the uncini in setigers 7-8 were avicular, the main fang was absent and all teeth were uniform in size, in a narrow, elongate, rasp-shaped arrangement. Companion setae were present in the neuropods of setigers 2-6 and absent in setigers 7-8. Abdominal notopodial uncini in setigers 9-11 were acicular, with the distinct main fang surmounted by a series of smaller teeth.

Remarks: this species has been recorded living in galleries of the shells of various genera and species of marine gastropods in South Africa, including the abalone *Haliotis midae*, and in California there are records in the red abalone *Haliotis rufescens*.



Fig. 1: Detail of the shell of a red abalone (*Haliotis rufescens*) from Puerto Montt, Chile, on which the branchial crowns of *Terebrasabella heterouncinata* can be observed (Photo: F. Avilés).

Detalle de una concha de abalón rojo *Haliotis rufescens* de Puerto Montt, Chile en que asoman las coronas branquiales de *Terebrasabella heterouncinata* (Foto: F. Avilés).



Fig. 2: Lateral view of a complete specimen of *Terebrasabella heterouncinata* which was extracted from a shell of the red abalone *Haliotis rufescens* from Puerto Montt, Chile (Photo: F. Avilés).

Vista lateral de un ejemplar completo de *Terebrasabella heterouncinata* extraído de una concha del abalón rojo *Haliotis rufescens* de Puerto Montt, Chile (Foto: F. Avilés).

Dodecaceria cf. *opulens* Gravier, 1908

Diagnosis: we examined the external morphology of three specimens extracted from galleries that were dug into the shell of the red abalone *Haliotis rufescens* (Fig. 3) from Puerto Montt, Chile. The color of the fixed specimens was brownish-orange and green; individuals measured between 30 to 60 mm in length and 2 mm wide, with up to 120 setigers (Fig. 4). The prostomium is blunt, and forms a hood over the mouth. The buccal segment is long and blunt, but with two stout grooved palps at its junction with setiger one. In the peristomium and second segment there are two pairs of branchial filaments; from the third to the eleventh segment there is only one pair of branchial filaments; with those of the first two segments being very short. The first setiger is uniramous with simple capillaries. The second setiger is biramous and bears notopodial and neuropodial setae. The setae of the first 10 setigers are simple capillaries with a serrated edge. Beginning at setiger 11 there are stout, notopodial and neuropodial spoon-shaped hooks. The neuropodial hooks are the most robust.

Remarks: in this study we record, for the first time, the presence of *Dodecaceria* cf. *opulens* in the shell of red abalone (*Haliotis rufescens*) from Puerto Montt, Chile. Earlier, Rozbaczylo & Carrasco (1996) mention the presence of this species in the shells of the gastropod molluscs *Fissurella maxima* and *Concholepas concholepas*, as well as in the bivalve *Aulacomya ater*. Hernández et al. (2001) recorded this species in the shell of the barnacle *Austromegabalanus psittacus* in Concepción, Chile.

Polydora biocipitalis Blake & Woodwick, 1971

Diagnosis: we examined the external morphology of two specimens taken from a mud-blister in the shell of the clam *Mulinia edulis* (King & Broderip). These specimens were compared with specimens extracted from the shell of *Mesodesma donacium* (Lamarck) that were deposited in the Collection of Flora and Fauna "Professor Patricio Sánchez Reyes" (SSUC), of the Pontificia Universidad Católica de Chile in Santiago. The specimens were 18 mm long, with up to 110 setigers. This species

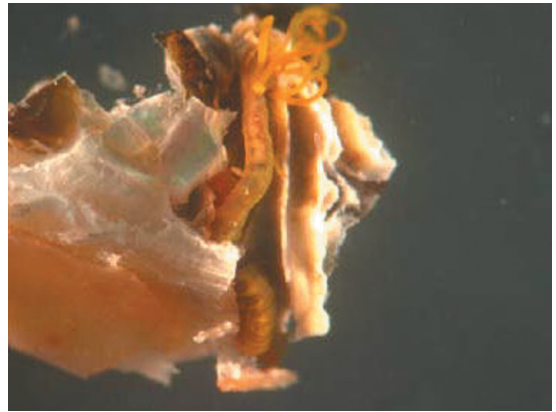


Fig. 3: A piece of shell from the red abalone *Haliotis rufescens* from Puerto Montt, Chile which has been bored into by a specimen of *Dodecaceria* cf. *opulens* (Photo: F. Avilés).

Trozo de concha de abalón rojo *Haliotis rufescens* de Puerto Montt, Chile perforado por un ejemplar de *Dodecaceria* cf. *opulens* (Foto: F. Avilés).



Fig. 4: Lateral view of a complete specimen of *Dodecaceria* cf. *opulens* extracted from a shell of the red abalone *Haliotis rufescens* from Puerto Montt, Chile (Photo: F. Avilés).

Vista lateral de un ejemplar completo de *Dodecaceria* cf. *opulens* extraído de una concha de abalón rojo *Haliotis rufescens* de Puerto Montt, Chile (Foto: F. Avilés).

is easily recognized by the following combination of characters: the prostomium is deeply notched on the anterior margin, with a caruncle that extends up to setigers 10-14, approximately; with two nuchal tentacles in a row located at the level of the first setiger and between the palps, immediately following the two pairs of eyes. Notosetae are absent on setiger one. Bidentate hooded hooks are present on the neuropodia beginning at setiger 10. The branchiae are long, blunt and wide, and begin on setiger seven, continuing to near the posterior end of the body. Setiger 5 is larger than other setigers and includes a curved row of 8 to 10 heavy spines alternating with pennoned

companion setae. The heavy spines are falcate and have three accessory structures. The pygidium is disclike, with a dorsal gap.

Remarks: in this study we recorded this species, for the first time, on the paleal sinus of a specimen of the clam *Mulinia edulis* (King & Broderip), collected in the locality of Playa Santo Domingo, south of the port of San Antonio, Chile. Earlier, Rozbaczylo et al. (1980) recorded this species in the shell of live specimens of the bivalve *Mesodesma donacium* in Playa Morrillos. Blake (1983) recorded this species in Playa El Aguila, approximately 100 km south of Iquique, Chile in shells of live *Mesodesma donacium*.