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Down under the southeastern Pacific: marine non-indigenous species in Chile

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Abstract

This article presents the first compilation of marine non-indigenous species (NIS) of algae and macro-invertebrates invading Chilean waters. A total of 32 cosmopolitan and non-cosmopolitan species are reported. Among them there are six species considered as extending their southern range of distribution in connection with El Niño events. The article highlights negative and positive impacts caused by marine NIS invasions. Among the first are *Codium fragile* var. *tomentosoide*, considered as a pest in *Gracilaria chilensis* aquaculture facilities in northern Chile, and *Ciona intestinalis*, a pest in scallop aquaculture installations. Among the second are bio-engineers species, such as the ascidian *Pyura praeputialis* and the sea grass *Heterozostera tasmanica*, which have caused an increase in local biodiversity and enhancement of nursery grounds *via* the creation of new habitats. Further more, invaders such as the algae *Mastocarpus papillosus*, *Porphyra linearis* and *P. pseudolinearis* represent new exploitable resources, extracted by coastal food gatherers along the coast (*M. papillosus*) or potential species to develop aquaculture. Additional information is presented on the anemone *Anemonia alicemartinae*, which appears to be a native species (?), having shown in the past 40–50 years, a geographical southward range extension of approximately 1900 km. The number of NIS reported for Chile is compared with those published for the southwestern Atlantic, South Africa, North America (Atlantic and Pacific coasts) and New Zealand. It is suggested that probably the low number of Chilean NIS is due to the fact that the Chilean coasts are environmentally less stressed than other coasts in the world, due to the scarcity of estuaries, gulfs, enclosed bays, lagoons and low human populations. These kinds of sheltered areas have been suggested as centers for bio-invasions, due to the high rate of human-mediated transfer and increase of pollutants. Furthermore, none of NIS reported from Chile show a fast geographical expansion rate (exception of *A. alicemartinae*), nor invading strategies such as those described for marine NIS in other latitudes, where notorious ecological unbalances following invasions have been observed. An alternative hypothesis is that the low number of marine NIS invading Chile is underestimated, since the modern list of species generated through specific taxonomically intensive port and harbor surveys is still lacking. Fifteen

species (five invertebrate and 10 fish) have been deliberately imported to Chile for aquaculture. The invertebrates appear to be controlled within aquaculture facilities and have not established naturalized populations or caused direct ecological impacts on local communities. On the contrary, several millions of salmoniforms (and rainbow trout) have escaped from farming facilities in southern Chile and established naturalized populations. Studies on ecological impacts are lacking. These escapees are also playing a role in the enhancement of artisanal and sport fishery activities.

Introduction

The accelerating invasion of marine systems by non-indigenous species (NIS, Carlton 1996) through ballast water, species transported on ship hulls and intentional and/or accidental introduction of species for aquaculture, has become a subject of environmental concern (Carlton and Geller 1993; Carlton 1996, Vermeij 1996, Ruiz et al. 1997, 1999, 2000; Cranfield et al. 1998; Orensanz et al. 2002). Numerous marine NIS have been identified as stressors, affecting native species, communities structure and function and ecosystems (D'Antonio and Vitousek 1992; Baskin 1998; Steffani 2001; Orensanz et al. 2002, Robinson and Griffiths, 2004) and vectors of negative changes affecting local economies and human health (Hallegraeff 1998; Bryan 1999; Harvell et al. 1999). According to Orensanz et al. (2002), an overwhelming majority of publications on marine NIS invasions correspond to North America, Europe, Australia and New Zealand (also see Ruiz et al. 1997, 2000; Vásquez and Aragón 2002). Latin America, Africa, the Indian Ocean and the southeastern Pacific appear poorly represented. This may be due to a lack of knowledge based on specific marine NIS surveys, publications and/or that some of those regions are less affected by marine NIS invasions and environmental impacts. Along the coasts of Latin America, particularly in South America, the extent of marine bio-invasions has been poorly reported. Nevertheless, when expert survey efforts have been made, as for instance in Argentine by Orensanz et al. (2002) along the Patagonian Shelf Large Marine Ecosystem, the results indicated that those ecosystems cannot be considered pristine confines of the world any longer.

The southeastern Pacific coasts of South America have been exposed to around 500 years of international shipping activities (Maino 1985; Larraín 2001) with the potential to inoculate them with marine NIS. Before the opening of the Panama Channel in 1914, the European ship routes to the west coast of South America around Cape Horn were compulsory. Chilean ports were key in trading. Furthermore, for about a century (1840–1940), international whaling, 'guano' bird and 'nitrate' fleets were based in northern Chile ports. Ports such as Iquique, Antofagasta and Valparaíso were central to such activities (Maino 1985; Arce 1997). Moreover, the advanced modern-day advent of aquaculture in Chile, that has imported many extralimited species (mentioned later), is based on species introduction programs, which started more than a century ago (Basulto 2003). In spite of the above, very little is known of the extent of the diversity, ecological impacts, economical consequences and/or health problems caused by marine NIS invasions in Chile.

In Chile, as in other South American countries, taxonomic knowledge and the reduced number of active marine taxonomists are major sources of uncertainty regarding modern marine species lists, and this may be one of the causes behind the lack of recurrent reports on marine NIS invasions. Also, there is a lack of specific, taxonomically intensive port, bay and harbor surveys, looking at the fouling and boring organisms on port pilings, wharves, docks, marina floats, and in the soft-bottom benthos under these structures. In spite of this, throughout Chile, major marine taxa are documented to an extent that ecological and biogeographical patterns, mostly regarding benthic communities, have emerged (i.e. Viviani 1979; Brattström and Johanssen 1983; Valdovinos, 1999, 2001; Fernández et al. 2000; Camus 2001; Valdovinos et al. 2003). Furthermore, Chile exhibits a long-standing tradition of national and international marine taxonomic efforts (i.e. Molina 1782; Gay 1847–

1854; Plate 1898–1913), and in the past, the country has been the focus for several international marine-collecting expeditions (i.e. Challenger Expedition 1872–1876, Lund University Chile Expedition 1948–1949). Numerous additional investigators have studied coastal benthic communities and biogeography in Chile (i.e. Marincovich 1973; Sebens and Paine 1979; Santelices 1980, 1991; McLean 1984; Moyano 1991; Castilla et al. 1993; Desqueyroux-Faúndez and Van Soest 1996; Rozbaczylo and Simonetti 2000). This makes it less likely that if numerous/abundant marine NIS invasions were present in Chile, and their ecological effects been marked, they may have gone ignored (but see Philippi 1881; Phillips et al. 1983; Avila and Alveal 1987; Castilla et al. 2002a).

In this review, we make the first attempt to update and compile a database for benthic macro-invertebrates and macro-algae (adding three cases for copepods) that have invaded or been imported (i.e. for invertebrate and fish aquaculture) to Chile. The work is based on a cooperative effort by several Chilean marine scientists with knowledge on diverse marine taxa. In the literature, there are two reports addressing, in general terms, the status of marine NIS in Chile (Poblete and Alvial 1993; Báez et al. 1998; also see Vásquez and Aragón 2002). Our review explores the idea that from a comparative point of view (i.e. in contrast with marine NIS invasions reported for the coasts of the southwestern Atlantic, South Africa, North America and New Zealand), the Chilean coast may present a reduced marine NIS invasion pattern and one on which the stressor role on local systems by NIS is still incipient. We suggest and discuss the major causes that may explain these patterns.

Scope and criteria used

Criteria for inclusion

The criteria used for inclusion of marine NIS invasions approximately followed those listed by Orensanz et al. (2002): (1) Species imported for aquaculture, and (2) NIS whose status in Chile was (a) well documented in publications, theses, written reports, and/or based on the professional experience of the authors; (b) species that were reasonable candidates for the status of NIS according to (i) wide geographical distribution, including 'cosmopolite' species, and species showing notorious incongruous ranges of distribution, (ii) species showing invasive potential indicated by documented NIS status in other regions, (iii) species that were abundant in the vicinity of presumed centers of introduction (e.g. ports and harbors) but rare or absent from the rest of the studied region, (iv) species whose life history suggests long-distance dispersive potential, in particular on man-made structures (e.g. hull of vessels), or the ability to be dispersed via ballast water.

Criteria for exclusion

Species were excluded from the list if they met one or more of the following criteria: (1) cryptogenic species, not well documented for Chile in the literature as to be assigned to NIS or native species, (2) records existed of species reported exclusively on Chilean oceanic islands and Antarctica, (3) records existed on marine hydrozoans with a medusae stage, and medusa, since they often show wide geographical range of distribution which may be related to natural dispersion over the oceans, (4) records existed on marine wood-borer species, since usually they disperse widely on drifting woody substrata, (5) species that within the study region are exclusively associated with floating objects.

Results

Survey of NIS invasions into the southeastern Pacific (Chile)

Well-documented non-indigenous species

The results from the literature survey are summarized in Tables 1–3. Table 1 lists 19 cases for marine NIS invading Chilean waters, documented in two or more references and/or been repetitively collected: one sea grass, five algae, one sponge, two polychetes, three copepods, one mussel, four ascidians and two bryozoans.

The sea grass *Heterozostera tasmanica* was first collected by Philippi in 1864 (see Philippi 1881)

Table 1. Non-indigenous species (NIS) invading Chilean waters; documented in the literature at least twice and/or repetitively collected.

Taxonomic group	Species	Geographic distribution	Geographic distribution in Chile	Main references for Chile	Comments
Monocotyledoneae: Graminae: Zosteracea	*Heterozostera tasmanica* (Martens ex Aschers.) Den Hartong	Australia (south of 30°S): from Western Australia to New South Wales and Tasmania, ca. 44[a] S.	Puerto Aldea (30°17′ S, 71°37′ W), ca. 53 Km south of La Herradura de Coquimbo and Caleta Chascos, Salado Bay (27°41′ S; 71°10′ W)	Philippi (1881); Muñoz (1966); Den Hartog (1970); Phillips et al. (1983); González and Edding (1990)	First reported in 1864 as a sterile sea grass specimen from La Herradura, Coquimbo (29°58′ S, 71°18′ W). In 1980 and 1983 reported as a large sea grass plot from Puerto Aldea, Chile. In 1990 reported from Salado Bay
Chlorophyta Chlorophyceae	*Codium fragile* var. *tomentosoides* (Van Goor) Silva	Japan (site of origin), Europe, Australia, New Zealand, North America, Canada	Calderilla Bay (27°05′ S; 70°50′ W) and Caleta Zenteno (26°50′ S; 70°48′ W)	Neill et al. (2003); this paper	First reported in 1998. Personal communication (Dr J. Correa) as very abundant (pest) from Calderilla Bay, in *Gracilaria chilensis* sea farming facilities. Collected by Dr E. Martínez from Calderilla and samples deposited in Sala de Sistemática, PU Católica de Chile, Number SSUC 6913. Identification by Alejandra González. Also collected by J. Correa from Caleta Zenteno in intertidal pools (2002)
Rhodophyta Halymeniaceae	*Prionitis liyalii* Harvey	From Britsh Columbia (Canada) to Baja California (Mexico)	Mehuín (39°26′ S, 73°12′ W), Niebla (39°52′ S, 73°24′ W) , Ancud (41°52′ S, 73°50′ W)	Levring (1934); Westermeier and Ramírez (1978); Westermeier (1981)	Low intertidal, shallow subtidal species on flat, rocky platforms
Rhodophyta: Nemastomataceae	*Schizymenia pacifica* (Kylin) Kylin, 1932	Japan; Alaska (USA) to Baja California (Mexico)	Navidad (33°56′ S, 71°51′ W)	Ramírez and Rojas (1988); Hoffmann and Santelices (1997)	In central Chile, the individuals are found on rocks and boulders, inside shallow pools with frequent water exchange
Rhodophyta Gigartinaceae	*Mastocarpus papillatus* (C. Agardh) Kützing	Japan; Alaska (USA) to Baja California (Mexico)	Coliumo Bay (36°32′ S, 72°56′ W) to Golfo Arauco (36°51′ S, 73°09′ W)	Avila and Alveal (1987)	First recorded in Chile approximately in 1980. Known as 'luga gallo'. Low intertidal fringe and shallow subtidal area. Extracted by intertidal algae collectors. Commercial importance (personal communication, K. Alveal)

Rhodophyta Phyllophoracea	*Schottera nicaensis* (Lamouroux ex Duby) Guiry and Hollenberg	Mediterranean, Atlantic coast of Portugal, France, England, South Africa, Australia	Between Los Vilos (31°55′ S, 71°31′ W) and Concepcion (36°40′ S 72°59′ W)	Santelices (1989); Hoffman and Santelices (1997)	Common in the low intertidal fringe. Member of the shaded and exposed algal intertidal communities
Porifera Ancorinidae	*Stelleta clarella* (De Laubenfelds 1930)	Coast of California (USA)	Corcovado Gulf (42°53′ S, 73°55′ W) 50–95 m	Desqueyroux (1972) Desqueyroux and Moyano (1987)	Collection Museo de Zoología, Concepción, Chile
Polychaeta Spionidae	*Spiophanes bombyx* (Claparede 1870)	North and South Atlantic; Mediterranean; South Africa; Gulf of Mexico; Southeastern Australia: Falkland Island; West Canada to southern California; Bering Sea; Japan; Peru	Coliumo Bay (36°32′ S, 72°56′ W) Arauco Gulf (37°00′ S, 73°08′ W)	Carrasco (1974) Rozbaczylo (1985); Valdovinos (2001)	First in reported in Chile 1974 from Coliumo Bay. Dominant species in soft bottom subtidal environments (<30 m)
Polychaeta Spionidae	*Dispio uncinata* (Hartman 1951)	East and west coasts of North America; Gulf of Mexico (type locality); Central America, both sides of the Isthmus of Panama; Spain, Japan; Argentina	Viña del Mar (33°31′ S, 71°34′ W)	Foster (1971); Rozbaczylo (1985)	First in reported in Chile in 1971 from Viña del Mar
Crustacea: Copepoda	*Centropages abdominalis* (Sato 1913)	Boreal and temperate waters of the North Pacific	Ensenada Baja (45°27′ S, 72°49′ W), in Aysen Fjord, Chile	Hirakawa (1986)	First collected in Chile in 1980–1986. ProbablyIntroduced via ballast water
Crustacea: Copepoda	*Acartia omori* (Bradford 1976)	Japanese waters	Ensenada Baja (45°27′ S, 72°49′ W), in Aysen Fjord, Chile	Hirakawa (1988)	First collected in Chile in 1980–1986. Probably introduced via ballast water
Crustacea: Copepoda	*Oithona davisae* (Ferrari and Orsi 1984)	Coast of California	Ensenada Baja (45°27′ S, 72°49′ W), in Aysen Fjord, Chile	Hirakawa (1988)	Collected in Chile between 1980 and 1986. Probably introduced via ballast water
Bivalvia: Mytilidae	*Mytilus galloprovincialis* (Lamarck 1819)	Cosmopolitan	Dichato 36°33 S′; 72°56′ W), Yaldad (43°7′60″ S; 73°43′60″ W),Castro (42°29′ S; 73°45′ W)	Toro (1998) Daguin (2000) Daguin and Borsa (2000): Hilbish et al. (2000)	First reported in Chile from Castro in 1998. Based on nuclear DNA information, the species was introduced to Chile from the Mediterranean (Daguin 2000)

Table 1. (Continued)

Taxonomic group	Species	Geographic distribution	Geographic distribution in Chile	Main references for Chile	Comments
Ascidiacea Pyuridae	*Pyura praeputialis* (Heller 1878)	Australia and Chile (Antofagasta). Isolated individuals also reported in Tahiti (French Polynesia)	Antofagasta Bay, Chile (23°38′ S, 70°24′)	Guiler (1959a) Paine and Suchanek (1983); Kott (1985, 1997, 1998); Clarke et al. (1999); Castilla (1998); Castilla et al. (2000, 2002a); Castilla and Guiñez (2000); Guiñez and Castilla (2001); Cerda and Castilla (2001)	First reported in the literature in1959. Probably established in Antofagasta Bay for a few hundred years. In Chile, intertidal and subtidal populations found exclusively inside the bay of Antofagasta, along approximately 70 km of coastline. Intertidal and shallow subtidal populations along several 1000's km in Australia
Ascidiacea Polycitoridae	*Ciona intestinalis* (Linnaeus 1767)	North Atlantic Ocean	From Strait of Magellan to Antofagasta	Traustedt (1885); Van Name (1954); this paper	First reported in Chile in 1885. Common on scallop aquaculture ropes (Tongoy, Caldera, Bahia Inglesa, Santa Maria Island, Antofagasta, personal observations J.C. Castilla and M. Clarke)
Ascidiacea Styelidae	*Asterocarpa humilis* (Heller 1878)	Southern temperate seas. West and south Australia (W & S), New Zealand, South Africa, Eastern Pacific	Juan Fernández (33°49′ S, 79°00′ W) and Antofagasta Bay (23°38′ S, 70°24′ W)	Clarke and Castilla (2000); this paper	First collected in 1999 on suspended ropes in scallop aquaculture facilities in Island Santa María (Mejillones Peninsula) and Juan López (Antofagasta Bay). Reiteratively collected from the area during 2000–2003 (P. Manríquez and J.C. Castilla)
Ascidiacea Molgulidae	*Molgula ficus* (Macdonald 1859)	Indo-Pacific	Antofagasta Bay (23°38′ S, 70°24′ W)	Clarke and Castilla (2000); this paper	First collected in 1999 inside intertidal matrices of *Pyura praeputilis* and in suspended scallop aquaculture ropes in Island Santa María (Mejillones Peninsula).Reiteratively collected from the area during 2000–2003 (P. Manríquez and J.C. Castilla)
Bryozoa Bugulidae	*Bugula neritina* (Linnaeus 1758)	Origin unknown	From Arica (18°28′ S, 70°18′ W) to Arauco (37°13′ S, 73°22′ W)	Moyano (1982) Moyano (1991)	As fouler on ship hulls and port piles
Bryozoa Bugulidae	*Bugula flabellata* (Thompson 1847)	Origin unknown	From Arica (18°28′ S, 70°18′ W) to Arauco (37°13′ S, 73°22′ W)	Moyano (1982) Moyano (1991)	As fouler on ship hulls and port piles

as a sterile sea grass specimen (drifting specimen?) at Herradura de Coquimbo Bay (ca. 30°S). This locality lies ca. 53 km north of Puerto Aldea, where this species has been reported as a well established, viable and dense sea grass plot (Muñoz 1966; Phillips et al. 1983). It might then be possible that Philippi's 1864 (see Philippi 1881) collection of *H. tasmanica* corresponded to a drift specimen from the Puerto Aldea's sea grass population. *H. tasmanica* is the only known sea grass established along the southeastern Pacific coast, and it appears to grow vegetatively, since it has never been collected in flower (González and Edding 1990). For about 126 years, no extension of the range of *H. tasmanica* was reported, until 1990, when González and Edding (1990) reported the existence of a second monospecific bed of the species north of Puerto Aldea at Caleta Chascos, Salado Bay (27°41′ S, 71°10′ W). At Chascos, the distribution of the sea grass is discontinuous, consisting of an assemblage of isolated patches, 2–10 m^2 in size. Ecological studies (subtidal benthic community trophic models) made by Ortiz and Wolff (2002) in the Puerto Aldea's *H. tasmanica* sea grass plot showed that these habitats have a productivity approximately three times higher than the present production of scallops, *Argopecten purpuratus* and the red algae *Chondrocanthus chamissoi* in the area.

Among the five species of algae (Table 1), two species are highlighted: (a) *Mastocarpus papillatus*, the 'luga gallo', first reported in Chile from Cocholgüe (36°36′ S, 72°58′ W) by Avila and Alveal (1987). According to a personal communication by K. Alveal the species most likely arrived in the area in the early 1980s on the hulls of ships associated with coal transport. At present, the species shows viable and dense populations from approximately Coliumo (36°32′ S, 72°56′ W) to the Golfo de Arauco (36°51′ S, 76°09′ W) in Concepción, and the populations appear to be expanding southward. Within this geographical range, the species shows high densities and is collected, under the local name of 'luga gallo', by intertidal algal collectors (K. Alveal, personal communication). No ecological studies have been done on the species. (b) *Codium fragile* var. *tomentosoides*, the 'Broccoli weed' or 'Dead man's fingers', originally from Japan, is a large branching green algae that may attain a length of almost 1 m and a weight of up to 3.5 kg. The species has recently invaded northern Chile's *Gracilaria chilensis* aquaculture facilities (Neill et al. 2003; J. Correa, personal communication), where it is considered a pest.

One species of sponge, *Stelleta clarella* and two species of polychetes, *Spiophanes bombix* and *Dispio uncinata*, are known invaders in southern and central Chile gulfs and bays. They represent classic cosmopolitan species in need for the taxonomy to be fixed (they may include several species).

The three species of copepods *Centropages abdominalis*, *Acartia omori* and *Oithona davisae* (Hirakawa 1986, 1988; Table 1), which occur regularly in boreal and temperate waters of the North Pacific, were collected in 1983 from fjords in southern Chile during the routine plankton-sampling program of the Japan International Cooperative Agency. Hirakawa (1986, 1988) states that the disjoint distribution of these copepods may be attributed to their introduction to Chile via ballast water transport. Nevertheless, so far, there is no published evidence for these species expanding along the Chilean coast.

The mussel *Mytilus galloprovincialis* (according to Daguin and Borsa 2000, erroneously reported from Chile by Toro 1998 as a sub-species of *Mytilus edulis*, also see Daguin 2000) has been collected in Chile from several localities, from Dichato (36°33′ S, Daguin and Borsa 2000) to Punta Arenas(53° S, Hilbish et al. 2000) (Table 1). According to Daguin (2000) and Daguin and Borsa (2000), based on nuclear DNA markers, the species was introduced to California and Chile from the Mediterranean. The present information indicates that so far, in Chile, the species is confined to mussel aquaculture facilities, and it appears that there are no naturally established populations in the wild.

Among the four species of ascidians (Table 1), the 'piure de Antofagasta', *Pyura praeputialis*, is highlighted. In Chile, the species is present almost exclusively in intertidal and shallow subtidal rocky habitats inside the Bay of Antofagasta (23°36′ S, 70°24′ W) (extending its range a few kilometers to the south and north of the bay), along approximately 60–70 km of the coast (Guiler 1959a; Paine and Suchanek 1983; Castilla

1998; Castilla et al. 2000), where its larvae appear to be retained (Clarke et al. 1999; Castilla et al. 2002b). Castilla et al. (2002a) based on Cytochrome Oxidase (COI) mitochondria sequences suggested that the species is a recent invader of Chile, probably arriving several hundred years ago from Australia. The exact date of the arrival of *P. praeputialis* is unknown, although there is 'oral history' of its presence in the bay at least for the past 75–80 years (Castilla et al. 2002a). The invasion is hypothesized to have occurred due to accidental human transport (e.g. ship hulls) and/or sea rafting from extant populations in Australia (Castilla and Guiñez 2000). Inside the Antofagasta Bay, *P. praeputialis* shows high densities (Castilla et al. 2000; Alvarado et al. 2001). The species is highly competitive for primary substrata (Guiñez and Castilla 2001), and in the part of the rocky mid-intertidal fringe at Antofagasta outcompetes the native mussel *Perumytilus purpuratus*. Probably, at the low-intertidal fringe, it also outcompetes the kelp *L. nigrescens* (Paine 1986; Castilla 1998; Cerda and Castilla 2001), thereby substantially modifying the rocky intertidal communities. Cerda and Castilla (2001) characterized *P. praeputialis* as an ecosystem bio-engineer species, which provides habitat (mid-intertidal fringe) for over 110 species of invertebrates and algae (also see Castilla et al. 2004). Finally, *C. intestinalis* (considered as a pest), *A. humilis* and *M. ficus* have been collected in northern Chile from scallop aquaculture ropes (Clarke and Castilla, 2000).

Two species of bryozoans, *Bugula neritica* and *B. flabellata* (Table 1), have been reported from ports (fouling communities) in northern and southern Chile and are considered cosmopolitan.

Reasonable candidates for NIS: species showing notorious biogeographical disjoint/incongruous ranges of distribution and a single documentation in the literature

Table 2 lists seven species: five algae, one sponge and one ascidian, which have been recorded once in the literature and are considered as reasonable candidates for NIS invasion of Chile. In most cases, the species (mainly for the algae) show a notorious biogeographical disjoint/incongruous range of distribution, particularly along the eastern Pacific. They are found mostly along the Alaska–Vancouver–California coasts and/or Japan (but are absent from the tropics) and in a few (single) localities in Chile. Further, the sponge *Mycale doellojuradoi* has been reported from off Mar del Plata, Argentine and Southern Chile. The ascidian *Botryllus schlosseri* is reported from Coquimbo in Chile and is also present in Europe, Australia, New Zealand and the east coast of USA.

Species that are reasonable candidates for NIS invaders in connection with the El Niño (ENSO) event and for which the Antofagasta Bay (northern Chile) plays a key role

Table 3 lists six species: two algae, one sponge, one polychete and two gastropods that appear to be reasonable candidates for NIS invaders of Chile, and for which the Antofagasta Bay plays a critical geographical distribution 'stepping stone' role. This bay has been documented as an 'upwelling shadow' (Castilla et al. 2002b; Lagos et al. 2002) and presents an almost constant sea water temperature frontal oceanographic structure across its mouth, with the surface temperature inside the bay being up to 2–4 °C higher than that outside (offshore, as well as along the coastline further to the north and south from the bay; Castilla et al. unpublished results). A cyclonic circulation and retentive meroplanktonic mechanisms have been shown to occur inside the bay (Castilla et al. 2002b). This group of NIS species have been collected in the Antofagasta Bay and also reported for one or two additional sites in northern Chile and Chilean oceanic islands. The four invertebrates (Table 3) are temperate to semi-tropical species, and there are reports indicating that viable populations have been found inside the Antofagasta Bay, linked with the initiation of 1982–1983 and 1997–1998 ENSO events, and/or with the initiation of scallop aquaculture activities (for the ascidians) inside and around the bay (Guzmán et al. 2001). For example, there is published evidence that the 'sea-hare' *Aplysia* (*A.*) *juliana*, a species characteristic of tropical and subtropical waters north of Paita, Peru (ca. 5°S), arrived in northern Chile associated with the intensive oceanographic 1982–1983 (Tomicic 1985) and the 1997–1998 ENSO events (the 1982–1983 ENSO event is considered the most intensive occurred in the 20th

Table 2. Reasonable candidates for NIS invaders to Chilean waters.

Taxonomic group	Species	Geographic distribution	Geographic distribution in Chile	Main references for Chile	Comments
Rhodophyta: Gloiosiphonaceae	*Schimmelmania plumosa* (Setchell) Abbott	Central California and Japan	Central Chile, Valparaíso (33°02′ S, 71°38′ W)	Santelices and Abbott (1978)	An infrequent species along the coast of central Chile. Plants usually found in deep, intertidal pools
Rhodophyta: Kallymeniaceae	*Pugetia mexicana* Dawson	Baja California (Mexico)	Mejillones Bay (23°04′ S, 70°27′ W)	Ramírez (1982)	In Chile is a subtidal species (between 10 and 15 m), living on mollusk shells
Rhodophyta: Bangiaceae	*Porphyra torta* Krishnamurthy	Washington State, Oregon, southern California	Montemar (Valparaíso) (32°58′ S; 71°29′ W)	González (1998)	First collection in 1996
Rhodophyta: Bangiaceae	*Porphyra linearis* Greville	Alaska, Canada, England	Montemar (Valparaíso) (32°58′ S; 71°29′ W); Laguna Verde (33°05′ S; 71°42′ W)	González 1998	First collection in 1996
Rhodophyta: Bangiaceae	*Porphyra pseudolinearis* Ueda	Japan	Montemar (Valparaíso) (32°58′ S; 71°29′ W); Laguna Verde (33°05′ S; 71°42′ W)	González (1998)	First collection in 1996
Porifera: Mycalidae	*Mycale doellojuradoi* (Burton 1940)	Off Mar del Plata (Argentina)	Estero Castro (Chiloé) (43°30′ S, 73°46′ W), 8 m	Hajdu and Desqueyroux -Faúndez (1994)	The specimen from Estero Castro conforms strictly to the material collected from Ushuaia, Tierra del Fuego
Ascidiacea: Botrillidae	*Botrylllus schlosseri* (Pallas 1766)	Europe, East coast of USA, Australia, New Zealand	Coquimbo Bay (29°56′ S, 71°21 W)	Van Name (1954)	First recorded in South America in 1948–1949 (University of Lund Chile Expedition)

Species showing a notorious biogeographically incongruous range of distribution, mainly along the Eastern Pacific coast. Single documentation in the literature.

Table 3. Species that are reasonable candidates for NIS invaders to Chilean waters via southern extensions of their geographical ranges in connection with El Niño (ENSO) events.

Taxonomic group	Species	Geographic distribution	Geographic distribution in Chile	Main references for Chile	Comments
Rhodophyta: Gigartinaceae	*Rhodoglossum affine* (Harvey) Kylin	From British Columbia (Canada) to California (USA)	Antofagasta Bay (23°38′ S, 70°24′ W)	Ramírez (1982)	A rocky intertidal species
Rhodophyta: Phyllophoraceae	*Ahnfeltia gigartinoides* J. Agardh	From British Columbia (Canada) to Ecuador	Antofagasta Bay (23°38′ S, 70°24′ W)	Ramírez and Santelices (1981)	Occurring at a depth of between 3 and 5 m
Porifera Timeidae	*Timea authia* (De Laubenfels 1930)	Laguna Beach, California (USA)	Antofagasta Bay (23°38′ S, 70°24′ W)	Desqueyroux (1972)	Intertidal species, small, encrusting on rocks. It has not been collected in other Chilean localities
Polychaeta Pilargidae	*Parandalia fauveli* (Berkeley and Berkeley 1941)	Southern California (USA); Gulf of Mexico; Central America, Guatemala; Bay of Ancón, Perú	Arica (18°28′ S, 70°18′ W), Iquique (20°11′ S, 70°08′ W), Mejillones Bay (23°04′ S, 70°27′ W)	Rozbaczylo and Quiroga (2000)	Specimens collected in Chile during the 1997–1998 El Niño event
Gastropoda Aplysiidae	*Aplysia (Aplysia) juliana* (Quoy and Gaimard 1832)	From Sonora (México) to Paita, (Perú)	Iquique (20°11′ S, 70°08′ W) , Antofagasta (23°38′ S, 70°24′ W) and Taltal (25°24′ S, 70°29′ W)	Tomicic (1985); Soto (1985); this paper	Sampled during the 1982 ENSO event, simultaneously from Iquique and Antofagasta. Two individuals collected in 1993 in Taltal by R. Bustamante and J.C. Castilla. Samples in the Sala de Sistemática, PU Católica de Chile, No. SSUC-6492. Identifications by Dr C. Paredes U.N. San Marcos, Perú and Dr S. Millen, U. of British Columbia, Canada.
Gastropoda: Ranellidae	*Linatella* (*L*) *wiegmanni* (Anton 1838)	From Baja California to Southern Peru	Antofagasta Bay (23°38′ S, 70°08′ W)	This paper	Viable populations in the Bay of Antofagasta, most probably established after the 1982 ENSO event

century, with an elevation of surface sea water temperature of up to 4–5 °C). The first report on the presence of this 'sea-hare' in Chile was from Antofagasta (ca. 23°50′ S) in 1982 and Iquique (ca. 20°S; Soto 1985) . In 1993, the species was collected, subtidally at around 8–10 m, from Taltal (ca. 25°S), where populations appear to have become established (sampling done by J.C. Castilla and R. Bustamante; unpublished sight records for 1993, 1996 and 1998 by J.M. Fariña). The polychete *Parandalia fauveli* was collected in northern Chile during the 1997–1998 ENSO event (Rozbaczylo and Quiroga 2000).

Two species of algae, *Rhodoglossum affine* and *Ahnfeltia gigartinoides*, are present along British Columbia, the west coast of the USA and the Equator (*A. gigartinoides*), and found in Chile exclusively inside the Antofagasta Bay. No studies on the ecological impacts caused by the invasion of this group of NIS have been conducted in Chile.

A native (?) Chilean anemone showing an important southward extension of its geographical range.

Anemonia alicemartinae (Haüssermann and Försterra 2001) is a conspicuous intertidal and shallow subtidal red anemone, recently described from Chilean waters, which appears to be a native species (so far no collecting efforts have been made in Peru), showing an important southward extension of its geographical range during the past 40 years. The species was not reported in intertidal or subtidal habitats during rocky intertidal and shallow subtidal surveys conducted by ecologists and anemone specialists around 1959–1965, either in northern or central Chile (i.e. Guiler 1959a, b; Carter 1965). The first known report for the species (referred to as *Actinia* sp.) was put forward by Sebens and Paine (1979), based on sea anemone collections made during 1975–1976 (R.T. Paine intertidal expedition to Chile) from Iquique (20°16′ S) and Punta Jara (23°49′ S). During this expedition, the species was not found south of this site, along 26 intertidal collecting sites down to 54°50′ S.

According to Häussermann and Försterra (2001, and personal communication by W. Stotz), in the 1980s, the species was common in Coquimbo (ca. 30°S). In 1994–1995, the species was not present in the intertidal area of the Bay of Concepción (ca. 37°S), where Häussermann and Försterra looked for it. Nevertheless, they found it inside this bay in 1998–1999 and in 2002, J.C. Castilla collected the species from mid-intertidal pools at Algarrobo (ca. 33°22′). Therefore, between 1975 and 1999, there was a southward invasion of *A. alicemartinae* of about 19° of latitude. Häussermann and Försterra (2001) suggested that (a) *A. alicemartinae* is an invasive species not recorded in the country of origin (i.e. Peru) that started to increase in abundance when it reached northern Chile between 1959 and 1975 and (b) that the geographical distribution of the species has not changed substantially, but originally was less abundant, and that ecological changes (discussed later) have led to increased abundance and colonization of intertidal habitats

Importation of marine invertebrate and fishes for mariculture

Fifteen marine non-indigenous species have been successfully imported to Chile for aquaculture. They include five invertebrates: the 'Japanese oyster' *Cassostrea gigas*, the 'red abalone' *Haliotis rufescens*, the 'green abalone' *Haliotis discus hannai*, the 'scallop' *Pecten maximus* and the 'Equatorian or white shrimp' *Litopenaeus vannamei*. The group also includes 10 species of fish: the 'king salmon' *Oncorhynchus tschawytscha*, the 'coho salmon' *O. kisutch*, the 'chum salmon' *O. keta*, the 'pink salmon' *O. gorbuscha*, the 'cherry salmon' *O. masou*, the 'red or sokey salmon' *O. nerka*, the 'Atlantic salmon' *Salmo salar*, the 'hirame' *Paralichtys olivaceus*, the 'halibut' *Hippoglossus hippoglosus* and the 'turbot' *Scopthalamus maximus* (Báez et al. 1998; Basulto 2003).

Among the invertebrates, two species have shown higher commercial success: *Crassotrea gigas*, imported to Chile in 1977 (5441 tons were cropped in 1999; Servicio Nacional de Pesca 1999) and *Haliotis rufescens*, imported to Chile in 1981 (48 tons were cropped in 1999). For these species, there is no information regarding the establishment of naturalized populations along the coast of Chile, and they appear to be under control within aquaculture facilities. Therefore, the import of invertebrates does not show direct

ecological impacts on native species, communities or ecosystems. Nevertheless, an indirect ecological impact can be singled out, as a result of the intensive extraction (hand-cutting) of the rocky intertidal kelp *Lessonia nigrescens*, which is used as abalone food in Chilean aquaculture facilities. The most affected rocky shores are those of central Chile at Los Molles (ca. 32°S) and Las Cruces (ca. 33°S) (J.C. Castilla, field observations and P. Manríquez, personal communication). *L. nigrescens* is a bio-engineer species (Jones et al. 1994) and a key component of Chilean intertidal rocky shore communities (Santelices et al. 1980). Therefore, 'red abalone' aquaculture activities in the country may be damaging (via uncontrolled extraction) the population structure and dynamics of this kelp and associated communities.

Efforts to import and introduce to Chile fish species for aquaculture have lasted for more than a century (Basulto 2003). In Chile, in the past 15 years, there have been over 300 fish aquaculture facilities developed (mainly in southern Chile and in most cases related to salmon farming). The species more intensively cultivated are *Salmo salar* (103,242 ton cropped in 1999) and *Oncorhynchus kisutch* (76,324 tons cropped in 1999).

Discussion

The relative importance of introduction in Chilean waters

There are few studies addressing marine NIS accidentally or intentionally introduced into Chilean waters (but see Phillips et al. 1983; González and Edding 1990; Poblete and Alvial 1993; Alvial et al. 1998; González 1998; Castilla and Guiñez 2000, Vásquez and Aragón 2002). Fewer studies address the ecological impacts and consequences for local communities, biota, ecosystems, economic activities and health (Báez et al. 1998). This review is the first comprehensive attempt to gather information on the subject, mainly addressing benthic coastal invertebrates and algae, and species imported in connection with aquaculture. We report a total of 32 marine NIS of algae and invertebrates (Tables 1–3) (out of which six are considered species extending their southern range of distribution in connection with El Niño events) and 15 species of invertebrates and fish introduced in Chile for aquaculture. These numbers can be compared: (1) with those reported by Robinson and Griffiths (2004) for the west coast of South Africa: 20 species of NIS and five species introduced deliberately for aquaculture purposes, (2) Orensanz et al. (2002) for the southwestern Atlantic Ocean, including coastal and shelf areas of Uruguay and Argentina: 31 species of NIS of invertebrate invaders and 46 cryptogenic species, (3) Ruiz et al. (2000) for North America: 298 NIS of invertebrates and algae established in marine and estuarine waters, (4) with those reported for New Zealand: 313 species of macroalgae and invertebrates (Crainfield et al. 1998). Hence, the total number of NIS invaders of Chilean waters is similar to that reported by Robinson and Griffiths (2004) (also for an upwelling coastline), but lower than that reported by Orensanz et al. (2002) and much lower than those indicated for North America and New Zealand. According to Ruiz et al. (1999), estuaries and sheltered coastal regions are frequent sites for marine invasions, probably due to the relatively high rate of human-mediated transfer, the increase of chemical pollutants and modification of thermal environments and sedimentation. These and other environmental stressors may have a strong influence on marine invasions. For instance, Ruiz et al. (1999) identified 196 NIS and cryptogenic species inside the Chesapeake Bay region, and Carlton and Cohen (1995) identified 211 NIS and 125 cryptogenic species for the Bay of San Francisco. Following Ruiz et al. (1999), in this paper, we argue that since the southeastern coast of South America, in particular the coast of Chile between approximately 18°–40°, almost completely lacks estuarine, gulfs and sheltered zones (with few exceptions south of 34°S), the expectation for NIS invasions will be comparatively lower than that for the USA Pacific and Atlantic coasts, southwestern Atlantic or New Zealand, where gulfs, bays, estuaries, coastal lagoons and shelter areas represent an important portion of the coast. These areas would act as focal NIS invasion points. Therefore, we consider two main hypotheses: (1) the low number of marine NIS invaders now reported in Chilean waters may not be seen as a surprise or lack of sufficient scientific

knowledge, but as a consequence for the existence of less stressed coastal ecosystems. For instance, in the southwestern Atlantic (see Orensanz et al. 2002), the Rio de la Plata and numerous shelter gulfs and coastal lagoons (i.e. Gulfs San Matías, Nuevo and San Jorge, Coastal lagoon Mar Chiquita) may play key roles as environmental stressors promoting NIS invasions. In fact, the three most dramatic NIS invasion reported by Orensanz et al. (2002), the 'golden mussel' *Limnoperna fortunei*, the laminarian *Undaria pinnatifida* and the polychete *Ficopomatus enigmaticus*, are linked to the Rio de la Plata, Golfo Nuevo and Mar Chiquita coastal lagoon areas, respectively. In Chile, south of 40°–41°S, the coast is extremely rugged, but sparsely populated and with only two major ports. The reports of Hirakawa (1986, 1988) regarding the invasion of three species of copepods (probably via ballast water, Table 2) may be connected with the fjord of Aysen and the port of Chacabuco (approximately 45°S). Following this argument, we predict, for instance, that the rate of marine NIS invasions along the central and southern coast of Peru may be similar to that reported along the Chilean coast and lower than that reported by Orensanz et al. (2002), roughly for the same latitudes, in the southwestern Atlantic. (2) An alternative hypothesis will be that in Chile the modern list of invasive marine species generated by doing specific, taxonomically intensive port and harbor surveys, looking at the fouling and boring floats, and in soft bottom benthos under these structures, is lacking, and therefore, the number of NIS invaders is underestimated.

Species invasions: aquaculture and coastal food gathering

Aquaculture activities are seen as promoters for NIS invasions. In Chile, there are several examples. The most conspicuous ones refer to cosmopolitan species: (1) the ascidian *Ciona intestinalis* (Table 1), which represents a serious fouling problem for invertebrate mariculture in the country (J.C. Castilla and M. Clarke, unreported observations), (2) the recent invasion to northern Chile of the 'Broccoli weed' pest *Codium fragile* var. *tomentosoide* (Neill et al. 2003, this paper; also see Carlton and Scanlon 1985; Trowbridge 1995, 1998), that is affecting *Gracilaria chilensis* aquaculture, (3) the mussel *Mytilus galloprovincialis* (Daguin 2000; Daguin and Borsa 2000; also see discussions in Toro 1998, Hilbish et al. 2000), reported for several localities in southern Chile.

The sea grass *Heterozostera tasmanica* (first reported as an invader in 1864) and the ascidian *Pyura praeputialis* (present in Chile at least for about a century; Castilla et al. 2002a) (Table 1), show viable and long-lasting populations and have remained constrained inside small bays in northern Chile: Puerto Aldea and Antofagasta respectively; although a northward range extension for *H. tasmanica* was reported in 1990 (González and Edding 1990). Both species may be used to illustrate marine NIS invasions causing positive impacts on local communities and enhancing coastal food gathering. For *P. praeputialis*, and edible sea-squirt, via the increment of the local bio-habitat, biodiversity and nursery grounds for invertebrates (Castilla and Camaño 2001; Cerda and Castilla 2001; Castilla et al. 2004) and for *H. tasmanica,* via the creation of new sea grass habitats (Ortiz and Wolff 2002). Another group of non-cosmopolitan species, mainly algae (Tables 1 and 2), have been recently reported (less than 20–25 years ago) as NIS invading Chilean waters. Among them, the red algae *Mastocarpus papillatus* (Table 1, Avila and Alveal 1987), *Porphyra linearis* and *P. pseudolinearis* (Table 2, González 1998; González and Santelices in press) represent resources used by intertidal food-gather collectors and show a potential for farming.

Species invasions: oceanography and biotic interactions

Within the marine NIS invaders considered in this paper, there are six species (Table 3) whose presence in Chile may be linked to natural oceanographic phenomena and physiographic characteristics of the coast, rather than to accidental or intentional human-related transport. For instance, the 'sea-hare', *A. juliana*, is a marine invasion from Peru that, in a first stage, expanded to the bays of Iquique and Antofagasta. Most likely, the invasion was coupled with the 1982 ENSO event, and later on proceeded

southward (to Taltal, approximately 25° S). This may represent an invasive 'jump range expansion' mechanism (Nathan 2001), in which a population expands its geographic range through the establishment of sequential viable populations along the coast (stepping-stone model). For that to happen, it may be necessary to have not only an intensive and persistent major oceanographic event, lasting long enough for the population to expand, but also the existence of coastal sea-pockets (stepping stones), where the 'anomalous conditions' (i.e. increase in water temperature, sea current modifications) prevail. The Bay of Antofagasta may play such a role. This Bay was recently described as a 'coastal upwelling shadow' (Escribano and Hidalgo 2001; Castilla et al. 2002b; also see Graham et al. 1992; Graham 1993; Graham and Largier 1997), where a permanent lens of warm sea water, up to 4 °C warmer than outside (offshore and along the coastline south and north of the bay), persists throughout the year. We suggest that the 'sea-hare' invasion, as well as the species listed in Table 3, of northern Chile may have utilized such a mechanism (Tomicic 1992; Guzmán et al. 2001).

The anemone *Anemonia alicemartinae* (probably a Chilean native species?) has also shown in the past 40–50 years a southward expansion of its geographical range of approximately 1900 km. Häusermann and Försterra (2001) argued that ecological changes in rocky intertidal and shallow subtidal communities in northern and central Chile, such as the intensification of grazing by the black sea urchin *Tetrapygus niger* (also see Castilla and Fernández 1998 and personal communication by W. Stotz) and the substantial increase of barren grounds, dominated by lithothamnioid-like algae (a substratum where *A. alicemartinae* is abundant), may have prompted its southward expansion.

Species invasions and ecological impacts

In this paper, we report the import of aquaculture in Chilean waters of five species of invertebrates and 10 species of fish. The high development and economic success of aquaculture in Chile has played a catalytic role in these importations. Nevertheless, information on the direct or indirect ecological impact by NIS aquacultured species on local systems is scarce. The five invertebrates introduced to Chile do not appear to have established naturalized populations in the country. This is contrary to the observations in Argentine Patagonian waters, where for instance, the 'Japanese oyster', *Crassostrea gigas*, has gotten out of control (i.e. specimens have escaped from aquaculture facilities) and populations are expanding at a high rate forming oyster-reefs in shallow bays (Orensanz et al. 2002). An explanation for the lack of uncontrolled expansion in Chile of this oyster may be the cooler water conditions which the species encounter along the coast, due to upwelling events in northern and central Chile, as compared with the Atlantic (i.e. differences in surface sea water temperature between the Pacific and the Atlantic, for the same latitude, range between 3 and 6 °C), or cold water conditions in the Patagonian Fjord sector. *C. gigas* needs temperatures of about 20 °C to reproduce in nature (Bacher and Baud 1992). On the contrary, the rearing of abalone in Chile may constitute a serious threat to intertidal beds of the brown kelp *Lessonia nigrescens* (Santelices 1980; Santelices 1982; Ojeda and Santelices 1984) since the species is heavily extracted to satisfy food requirements for 'red-abalone' culture, mainly along central Chile.

In Chile, there is a lack of published studies regarding the environmental impact caused by the imported species of fish. In many cases, introduced species have created ecological and social conflicts. Salmon sea ranching, particularly due to the feeding methods used, may cause serious onsite negative impacts, such as water eutrophication or direct damage to the sea bottom (anoxic sediments) and/or to benthic communities under or around the fish cages (Soto and Mena 1999; Soto and Jara 1999). Worldwide, there is a growing concern regarding environmental impacts derived from intensive fish sea ranching. Furthermore, according to Soto et al. (2001), during heavy storms in 1994–1995, salmon farms in southern Chile lost several million salmon (*Salmo salar* and *O. kisutch)* and the rainbow trout, *Oncorhynchus mykiss*. There is no precise account for the damages caused to the native marine fauna and communities via these escapees

neither is there an estimate of the positive impacts (i.e. increase in small-scale fisheries and sport fishing) that salmon or rainbow trout escapees may have produced. On the other hand, mariculture of NIS has been considered one of the major gateways for the introduction of exotic marine species (Naylor et al. 2001). Two of the main ecological threats mentioned by these authors are their potential as 'biological polluters' (i.e. accidental escapees from aquaculture facilities) and the role played by parasites, pathogens and predators that are usually introduced along with the imported species.

Species invasions and geographic range extension

None of the 32 NIS of invertebrates and algae and 15 species imported for aquaculture, reported in this paper as invaders of Chilean waters, have had fast geographic expansion rates nor have these species used invading strategies such as those described in the southwestern Atlantic for *Limnoperna fortunei* (Pastorino et al. 1993; Darrigran and Ezcurra de Drago 2000), in the La Plata estuary, for the barnacle *Balanus glandula* (Vallarino and Elías 1997; Elías and Vallarino 2001), the laminarian *Undaria pinnatifida* (see Píriz and Casas 1994) or for the west and east coasts of South Africa for *Mytilus galloprovincialis* (Robinson and Griffiths 2004). These species have invaded and spread significantly for 30–50 years from their place of initial introduction and have had a substantial impact on local biota. In these and other examples, the NIS invaders have conquested the available intertidal or subtidal substrata (and water column) to expand at a fast rate and, in many cases, outcompeted native species, notoriously modifying communities and ecological balances. Similar experiences have been reported for the northern hemisphere coastal communities (i.e. Carlton 1979, 1985, 1987; Carlton and Geller 1993; Southward et al. 1998; Gerard et al. 1999).

Conclusions

We tentatively conclude that the coast of Chile, most probably due its physiographical configuration and oceanographic setting (Castilla et al. 1993 and the preceding discussion), cannot be considered to be environmentally highly stressed, leading to a large number of aggressive invasive species, such as those reported for the coasts of the southwestern Atlantic (Orensanz et al. 2002), New Zealand (Cranfield et al. 1998) or North America (Ruiz et al. 1997, 1999). Furthermore, in this review, we have identified cases in which NIS invaders (i.e. *Pyura praeputialis*, *Heterozostera tasmanica*, *Mastocarpus papillatus*) may have caused positive ecological impacts via the enhancement of local biodiversity (Castilla et al. 2004; also see Crooks 2002), nursery grounds and/or in connection with commercial exploitation. Exceptions to the above appear to be invasions of NIS considered as pests in mariculture activities, such as *Ciona intestinalis* and *Codium fragile* var. *tomentosoides*. Undoubtedly, further ecological studies on environmental impacts caused by NIS invaders of Chilean waters are needed. Perhaps, the same appreciation cannot be applied to the Chilean import of NIS for aquaculture, where salmonids and abalones may have caused a direct or indirect negative ecological impact on local fauna and flora. A balance between the need for the development of aquaculture activities in the country, leading towards economical development, and the due care for natural ecosystems needs to be achieved.

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