

Reconstructing the history of human impacts on coastal biodiversity in Chile: constraints and opportunities

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ABSTRACT

1. Although Chile is at the forefront in evaluating experimentally the importance of human harvesting impacts on coastal biodiversity, there are no evaluations of such impacts on a long-term historical basis (tens to thousands of years). Different types of archival information (i.e. contemporaneous, archaeological, and palaeontological) were used to carry out a research programme based on the historical assessment of the impacts and intensity of resource extraction on coastal biodiversity along the Chilean coast.

2. In addition to recent scientific literature, different sources of contemporaneous information (e.g. museum collections, old reports and accounts) can reveal the human impacts observed in the more recent past. Furthermore, the large number of prehistoric shell middens along the entire Chilean coast offer access to ~11 000 years of history along the entire coast, although the faunal composition, structure, and dynamics of most of them remain largely unstudied.

3. Finally, the rich and widespread fossil record of some marine groups provides the opportunity to reconstruct the structure and dynamics of benthic communities during different phases of human influence (e.g. pre-human, prehistoric harvesting, and modern harvesting).

4. Preliminary comparisons of fossil versus modern bivalve assemblages suggest marked changes in the species composition. Human impacts seem very recent and shifts in the structure of benthic assemblages may have occurred only a few centuries/decades ago.

5. In contrast, prehistoric harvesting, although intense, was apparently not enough to cause a profound impact on coastal ecosystems. The approach herein envisaged can provide the basis to build a historical baseline to evaluate the human impacts on the coastal biodiversity in the region.

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INTRODUCTION

Human use of coastal resources dates back more than 160 000 years, when early *Homo sapiens* ventured to coastal areas in South Africa (Marean *et al.*, 2007). Nowadays, more than 1.2

billion people (~23% of world's population) around the globe live within 100 km of the coast, and predictions suggest that this proportion will increase to 50% by 2030 (Small and Nicholls, 2003). There is a growing body of evidence that shows that marine coastal ecosystems, once considered by

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many as relatively pristine environments, have suffered profound alterations, ranging from species to ecosystem levels, including reductions in population sizes, shifts in geographic ranges, and loss of diversity, biomass, and ecosystem functioning (Pauly *et al.*, 1998, 2003; Jackson, 2001; Jackson *et al.*, 2001; Jackson and Sala, 2001; Hughes *et al.*, 2003, 2005; Helmuth *et al.*, 2006; Sala and Knowlton, 2006; Worm *et al.*, 2006).

Recent syntheses suggest that among all the types of human disturbances to marine coastal ecosystems, overfishing is the most significant, outweighing even pollution and climatic change (Jackson, 2001; Jackson *et al.*, 2001; Lotze *et al.*, 2006). However, ecological evaluations of human disturbances provide, in most cases, only minimum estimations of the real magnitude of the impacts, as these are measured against baselines established only a few years, or decades ago. A different perspective, integrating historical information, is needed in order to provide more robust baselines. Pioneer studies have combined information from fossil, archaeological, and historical records, to reconstruct the structure of marine assemblages across much longer timescales (Jackson *et al.*, 2001; Pandolfi *et al.*, 2003; Griffiths *et al.*, 2005; Lotze *et al.*, 2006; Worm *et al.*, 2006). These studies have demonstrated that even a couple of centuries ago, several coastal ecosystems were already heavily altered by human activities. They show that new methodological strategies, combining different disciplines, may improve our understanding of the long-term dynamics of marine assemblages, crucial to the development of effective conservation and management programmes. However, such studies have been focused on particular groups of species, and geographic regions. This study explores the feasibility of the application of this approach to evaluate the magnitude and timing of human impacts on the biodiversity of Chilean coastal ecosystems.

Overfishing is the most relevant and widespread human disturbance to coastal communities (Castilla, 1999; Fernandez *et al.*, 2000; Castilla and Defeo, 2001). The sea surface temperature has warmed up only weakly (0.43°C on average) during the last 50 years in the south-eastern Pacific region, three times less than observed in other regions of the ocean (Rivadeneira and Fernandez, 2005). At the same time, the impacts of other human disturbances (e.g. pollution) are very restricted along the coast, particularly to large cities, harbours and coastal areas with nearby mine tailings (Fernandez *et al.*, 2000). In contrast, landings from Chilean fisheries are among the highest in the world (FAO, 2007) and include a wide diversity of fish, invertebrates, and algae.

There have been a number of studies looking at the impact of contemporary human activities on coastal marine ecosystems in Chile (Castilla, 1999; Fernandez *et al.*, 2000; Moreno, 2001; Fernandez and Castilla, 2005; Thiel *et al.*, 2007). The impact of overfishing on coastal communities has been demonstrated experimentally by numerous studies over the last two decades (Moreno *et al.*, 1984, 1986; Castilla and Duran, 1985; Oliva and Castilla, 1986; Castilla and Bustamante, 1989; Duran and Castilla, 1989; Godoy and Moreno, 1989; Castilla, 1999, 2000; Moreno, 2001). The exclusion of humans from nature reserves has demonstrated that overfishing creates a cascade of effects in the diversity and abundance of species (Castilla, 1999, 2000; Moreno, 2001) giving rise to a different community structure, which has been taken implicitly as the 'pristine' baseline to assess human

impacts. Despite the lessons learned from these studies, it is hard to extrapolate results based on small-scale human exclusions (i.e. from only hundreds of metres of coast), in the rocky intertidal to the regional scale. Furthermore, human activities may have shifted the structure of natural assemblages a long time ago (e.g. ten to hundreds of years), as observed in several other ecosystems (Jackson *et al.*, 2001; Pandolfi *et al.*, 2003; Griffiths *et al.*, 2005; Lotze *et al.*, 2006; Worm *et al.*, 2006), invalidating modern baselines.

THE HISTORICAL APPROACH: METHODOLOGICAL CONSIDERATIONS

For practical reasons, the analysis is restricted to macro-invertebrates, for which the impacts of harvesting are usually more evident and there is information on modern and ancient assemblages. At least three methodological issues need to be carefully considered in order to carry out this historical analysis:

Timeframes

Unlike many palaeoclimatological proxies, there is no way of accessing continuous and long-term ecological records spanning hundreds to thousands of years. However, the combined use of three different kinds of sources of information (palaeontological, archaeological, and historical) gives access to different timeframes (Figure 1), with different degrees of temporal and spatial resolution. For instance, Quaternary terraces are available only for interglacial stages. Holocene terraces encompasses the period between ~7000 and 500 years ago, and sub-fossil assemblages (i.e. dead assemblages) may reveal information ranging from several decades to centuries ago (Flessa and Kowalewski, 1994), which thus far, have not been studied along the Chilean coast. The archaeological record (shell middens) is potentially much more continuous and characterizes different cultural phases of human occupation, since the arrival of the first human groups in the late Pleistocene (Dillehay and Collins, 1988; Santoro *et al.*, 2005) to colonial times (*ca* 16th century). Finally, the historical record composed of scientific and anecdotal information, in the form of papers, reports, accounts, or museum collections, can be traced back to the mid- 19th century, when a number of naturalists started to describe the flora and fauna of the country (Fernandez *et al.*, 2000; Camus, 2005; Castilla *et al.*, 2005).

Study model

Not all taxa are equally suitable for this approach. Taxa with hard parts are more prone to leave a record (sub-fossil, fossil, or archaeological). These include gastropods, bivalves, echinoderms, fish, marine mammals, and seabirds. For several reasons, gastropods and bivalves ('molluscs' hereafter) are particularly attractive as a study model: (i) molluscs have a high preservation potential (Foote and Sepkoski, 1999); (ii) are very diverse and abundant and have important ecological functions in the shallow benthic assemblages in Chile (Lancellotti and Vasquez, 2000; Valdovinos *et al.*, 2003); (iii) several species are being heavily exploited by small-scale artisanal fisheries (Castilla and Defeo, 2001; Leiva and Castilla, 2001); (iv) long-term historical

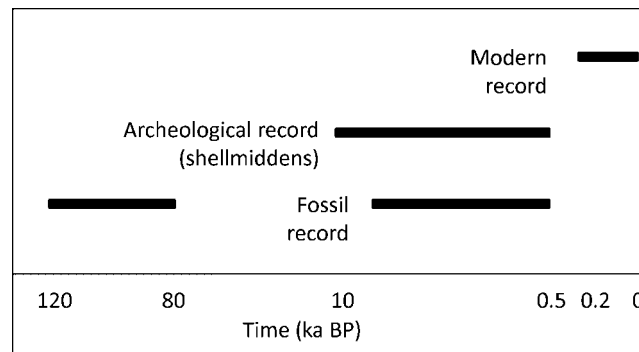


Figure 1. Timeframes accessed by different archives. The fossil record is only available for interglacial periods, during high sea-levels stands. The archaeological record offers almost a continuous record during the entire Holocene, ending around the time of the Hispanic Conquest. Information of modern assemblages is restricted to the last two centuries (see text for an explanation).

records (e.g. museum occurrences, fisheries statistics), are available for many of them; and (v) molluscs were highly valuable items in the diet of prehistoric coastal people of northern Chile, at all times. For more restricted comparisons, other taxa may also be suitable. For example, marine mammal, fish, and bird species, which all have very good modern records but are poorly represented in Quaternary terraces, can be common items in archaeological shell middens (Llagostera, 1979, 1992; Schiappacasse and Niemeyer, 1984; Jerardino *et al.*, 1992; Pandolfi *et al.*, 2003), and therefore they could be used in comparative analyses.

Biological parameters

Perhaps the most difficult, yet obvious task is to define an appropriate measure of human impact. A number of parameters have been proposed to investigate human impacts over more restricted timescales (e.g. ecological) (Rochet and Trenkel, 2003), but many of them cannot be traced easily in the archaeological or fossil record. For the purpose of a longer temporal comparison, the parameter(s) should be potentially measurable across the entire timeframe. For example, body size, an easily measured trait, and a good proxy for physiological, life history, and ecological features (Peters, 1983; Calder, 1996) is available in fossil, archaeological and modern assemblages. A reduction in body size is predicted under either size-selective harvesting or heavy overfishing (Pauly *et al.*, 1998; Rochet and Trenkel, 2003; Fenberg and Roy, 2008). Another good measure of human impact is species abundance, which is expected to decrease if overfishing takes place. Abundance can be estimated in the archaeological or fossil record either directly, at a local scale, or indirectly by using surrogate measures such as site-occupancy at regional scales (e.g. modelling the site-occupancy, MacKenzie *et al.*, 2006). A temporal decline in the relative abundance of target species has been used as an indication of large impacts (Pandolfi *et al.*, 2003; Lotze *et al.*, 2006). At community level, traditional parameters (e.g. species richness, composition, relative abundance, trophic levels) could be measured (Rochet and Trenkel, 2003; Rochet *et al.*, 2005). Here, the prediction is that heavily overfished systems will show lower species richness, shifting compositions (towards the absence of harvested species), and an overall reduction in the trophic levels (Trenkel and Rochet, 2003; Pauly *et al.*, 2005; Lotze *et al.*, 2006). Finally, different measures of human impacts

can be combined in a multi-proxy approach, creating ordinal categories of human impact (Pandolfi *et al.*, 2003; Lotze *et al.*, 2006). Thus, the 'ecological state' (ranging from pristine to extinct) of a given site or region can be tracked across time (Pandolfi *et al.*, 2003; Lotze *et al.*, 2006).

RECONSTRUCTING THE HISTORY OF HUMAN IMPACTS ALONG THE CHILEAN COAST

Three questions that exemplify the usefulness of this approach to provide answers relevant for marine conservation are analysed: (a) When did coastal biodiversity shift from its 'natural state' away from a pre-human (e.g. Pleistocene), marine baseline?; (b) What was the impact of prehistoric harvesting on the biodiversity of coastal assemblages?; and (c) Is it possible to generate a Quaternary pre-human baseline, in order to assess the existence and magnitude of present-day human impacts? The state of knowledge needed to answer these questions, and the methodological and analytical approaches needed are evaluated. Although in some cases information is still limited and patchy, and answers are rather preliminary, the questions posed above would, at least, allow us to formulate working hypothesis that could be further tested.

HUMAN IMPACTS ON MARINE COASTAL ECOSYSTEMS OF CHILE DURING MODERN TIMES

Long-term ecological time series documenting trends in marine populations and communities in the country are limited, restricted to a couple of marine reserves, and typically spanning up to two decades (Castilla and Duran, 1985; Duarte *et al.*, 1996; Castilla *et al.*, 2007). Alternative ecological time series could be used to evaluate the magnitude of human harvesting spanning longer periods. For example, statistics of marine landings have been used to build global synoptic analyses of the evolution of fisheries, and used to evaluate the human impacts on marine fisheries in modern times (Pauly *et al.*, 1998, 2003; Froese and Kesner-Reyes, 2002; Worm *et al.*, 2006). Not surprisingly, the analysis of 52 taxa harvested by Chilean artisanal fisheries and listed in the fishstat database (www.fishstat.org) shows

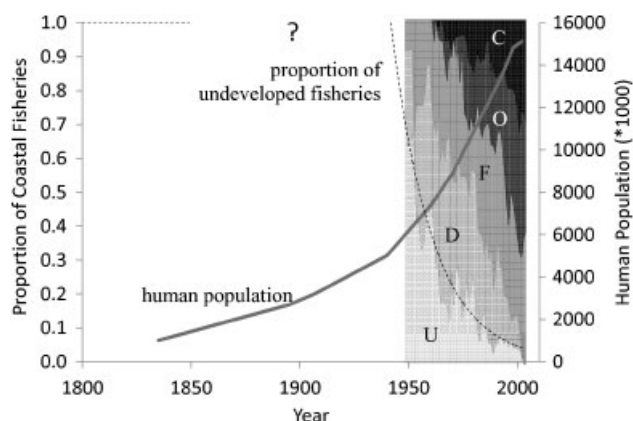


Figure 2. Decline in the proportion of undeveloped artisanal fisheries during last 50 years in Chile (U: undeveloped, D: developed, F: fully developed, O: overexploited, C: collapsed). Categories according to Froese and Kesner-Reyes (2002) classification. Data based on FAO statistics, for a total 52 artisanal fisheries (seaweeds, molluscs, crustaceans, echinoderms, and mammals) exploited in the country (available from www.fao.org/fi/statist). Superimposed is the estimated human population for the country (based on nationwide censuses between 1835 and 2002). The dotted line shows a backward projection of the proportion of species undeveloped.

that the number of collapsed fisheries has steadily increased to 30%, a situation that mirrors the global picture (Froese and Kesner-Reyes, 2002; Worm *et al.*, 2006). Conversely, the number of undeveloped fisheries in Chile declined exponentially from 1950 to the present (Figure 2). In 1950, *ca* 80% of fisheries were undeveloped. In contrast, in 2004 not a single Chilean fishery falls within this category, with most of them (70%) moving towards the overfished and collapsed categories. A retrospective projection of this pattern suggests that the ecosystem was in a 'pristine state' (e.g. 100% of fisheries undeveloped) at some point during the first decades of the 20th century, coeval with the increase in human population in the country. Thus, despite many fisheries not reaching their maximum level until the 1980s (Thiel *et al.*, 2007), the impact on them may have started several decades earlier.

Given the current state of knowledge, it is hard to cross-validate the existence of a recent shift in the structure of coastal ecosystems, additional archives may be necessary to provide further insights. For example, Castilla *et al.* (2005) took advantage of the historical accounts available (made by naturalists and international expeditions) to compile a database of benthic macro-algae and macro-invertebrates that invaded the country. Documentary information has also been used to reconstruct 'El Niño' chronologies since the 16th century in the region (Ortlieb, 1994, 2002). Recent studies in the Baltic region (MacKenzie *et al.*, 2007; Poulsen *et al.*, 2007) have recovered catch and effort data from a variety of archival sources (e.g. tax accounts, custom records, trade series, church accounts) extending back to the 15th century. In other cases, however, the information is not readily available in the form of reports, or papers, but is archived in the form of museum collections. Several authors (Burgman *et al.*, 1995; McCarthy, 1998; Shaffer *et al.*, 1998; Ponder *et al.*, 2001; Suarez and Tsutsui, 2004) have stressed the importance of museum collections as valuable sources of historical information. Using this approach, Roy *et al.* (2003) described a notable decline in the body size of several rocky intertidal species

during the 20th century in southern California, and attributed these changes to a series of direct and indirect effects induced by overfishing. Similarly, Rivadeneira and Fernández (2005) combined old references and museum collections to evaluate possible shifts in the southern range of distribution of several rocky intertidal species during the last 50 years in Chile. These authors did not find a clear directionality in the species' range shifts, and the magnitude of these changes was in general small compared with patterns reported for other intertidal species (Helmuth *et al.*, 2006). Similar protocols may be applied in order to reconstruct some other key aspects of the structure of coastal assemblages during the last decades in the region.

THE PREHISTORIC PHASE OF HARVESTING

Humans have been harvesting marine invertebrates and vertebrates in Chile since at least 12000 years ago, with the arrival of the first populations to the region (Llagostera, 1979; Aldenderfer, 1989; Sandweiss *et al.*, 1998; Santoro *et al.*, 2005). Analysis of shell middens along the temperate south-eastern Pacific coast reveals that indigenous populations extracted large amounts of molluscs including a high diversity of intertidal and shallow subtidal species (Llagostera, 1979; Reitz, 1988, 2001; Aldenderfer, 1989; Jerardino *et al.*, 1992; Siegfried *et al.*, 1994; Sandweiss *et al.*, 1996; Sandweiss, 2003; Baez *et al.*, 2004). The pervasiveness of human harvesting activities is revealed by a preliminary analysis, based on a literature review: 76% of rocky intertidal gastropods (42 out of 55 species) currently found along the coast of Chile (between 18° and 42°S) are recorded in shell middens of the region (Llagostera, 1979; Jerardino *et al.*, 1992; Vasquez *et al.*, 1996; Gaete *et al.*, 2004; Mendez and Jackson, 2004; Torres *et al.*, 2007).

The magnitude of the impacts of prehistoric harvesting on marine coastal assemblages, however, remains much less understood. Prehistoric impacts on coastal ecosystems are thought to be minimal worldwide (Pandolfi *et al.*, 2003), but several authors have pointed out cases of prehistoric over-exploitation (Mannino and Thomas, 2002; Pinnegar and Engelhard, 2007; Jerardino *et al.*, 2008). Indeed, this may be the case in the northern region of Chile. The extreme aridity of the Atacama Desert forced indigenous populations to rely almost exclusively on marine species as a source of food (Llagostera, 1979, 1992; Aldenderfer, 1989; Sandweiss *et al.*, 1998; Santoro *et al.*, 2005), which has been corroborated by isotopic analyses of mummy tissues (Aufderheide *et al.*, 1993; Aufderheide and Santoro, 1999). Furthermore, palaeopathological analyses suggest frequent and habitual contact with coastal cold wind and water, including diving in cold waters (Standen *et al.*, 1997), as well as the development of highly sophisticated tool kits for fishing, mollusc collecting, and sea mammals hunting, so it is possible that harvesting may also have occurred in shallow subtidal habitats. Indeed, according to historical accounts (Empeaire, 2002), Yamana women used to dive up to 8 m depth to collect shellfish in the cold waters of Tierra del Fuego region. The prehistoric populations of northern Chile were able not only to rely on marine resources, but also to develop a sedentary life based on marine resources, that included, molluscs, sea birds, sea mammals, and algae (Santoro *et al.*, 2005).

The current available information does not allow for a rigorous test of the impact of prehistoric people on coastal assemblages of the northern Chilean coast. Detailed accounts of the species composition and relative abundance across temporal sequences in shell middens are not available. However, the analyses of body size of harvested molluscs in shell middens may be used as an indicator of human impact (Jerardino, 1997; Milner *et al.*, 2007). For example, it is well known that prehistoric gatherers exploited intertidal populations of the muricid snail *C. concholepas* ('loco') more than 9000 years BP (Llagostera, 1979; Jerardino *et al.*, 1992; Baez *et al.*, 2004). The 'loco' fishery is currently overexploited (Buschmann and Pérez Matus, 2003), and studies conducted at marine reserves have shown the mean shell length of non-harvested populations of 'locos' is typically 2–3 cm larger than in open areas of the coast (Castilla, 1999; Moreno, 2001). Since the loco can be considered as a 'keystone' species, changes in its body size (and correspondingly in its abundance) may have dramatic and disproportionate effects on the entire intertidal community structure (Castilla, 1999). Therefore, the shell length of 'locos' could potentially be used as a benchmark to assess the impact of prehistoric harvesting on rocky intertidal assemblages: if the shell length recorded in shell middens is similar to the observed in present-day overexploited populations, then prehistoric overfishing may be concluded.

Ongoing archaeological study suggests that the impact of prehistoric populations between 4000 and 5500 years BP at the Camarones Punta Norte site (CPT, 19°S), where humans relied almost exclusively on marine species as a source of food, may have not been strong enough to produce a decline in the body size of 'locos'. The 'locos' from CPT (mean = 58 mm, $n = 878$) are on average 30% larger than in seven modern populations from southern Peru to central Chile (Figure 3), a difference that is statistically significant (t -test = -4.037 , d.f. = 6, $P = 0.007$). At the same time, the mean body size of 'locos' from the CPT is statistically not different from values reported for closed areas of the coast (t -test = -0.142 , d.f. = 1, $P = 0.909$), but this conclusion should be treated with caution given the low replication. It is unlikely that these patterns could be an artefact due to the intrinsic 'time-

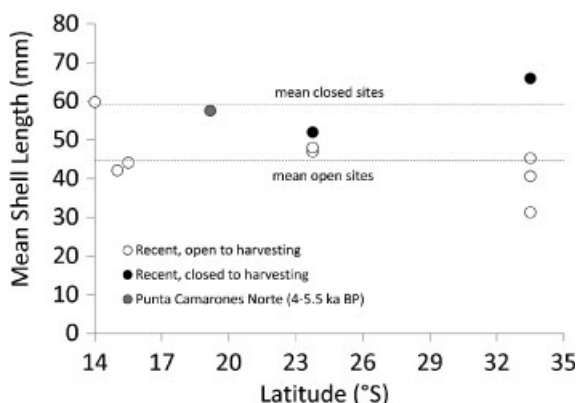


Figure 3. Comparison of the mean shell length of 'locos' (*Concholepas concholepas*) in modern rocky intertidal sites along the temperate coast of Pacific South America (open and closed to human harvesting) and the mean size recorded at a shell midden in the Punta Camarones Norte site (4000–5500 years BP) (58 mm, $n = 878$). Modern sites taken from Castilla and Duran (1985), Castilla and Rho (1996), Manriquez and Castilla (2001), and Rubio *et al.* (1999).

averaging' of shell middens. In the long term, and given a stable age structure, the mean body size of a population should not vary drastically. Therefore, the size structure of shells accumulated over time (i.e. tens to hundreds of years) should not be biased. Altogether, the evidence suggests that ~4000–5500 years BP the prehistoric impact on the body size of 'locos' may have been only mild, far from present-day high levels of extraction. However, detailed time series analyses encompassing larger timescales are needed in order to evaluate robustly the role of prehistoric populations, especially during mid- and late-Holocene when human settlements showed dramatic collapses and recoveries in the region (Williams *et al.*, 2008).

Similar studies carried out at central Chile (i.e. 30–33°S) have yielded mixed results (Jerardino *et al.*, 1992; Baez *et al.*, 2004). On the one hand, Jerardino *et al.* (1992) reported a marked decline in the shell size of *C. concholepas* observed during an ~8000 years period of occupation, from 9000 to 1300 years BP at the Curaumilla site (33°S). However, Baez *et al.* (2004) presented data showing no decline in the shell size of *C. concholepas* at Los Vilos site (ca 32°S) during a ca 4500 years occupation period (9200–3900 years BP), during the mid-Holocene. These results suggest that human impacts were spatially variable and/or the resilience of rocky intertidal communities to human impacts was variable along the coast. Other key questions, including the role of temporal changes in the palaeoceanographic conditions (e.g. palaeoproductivity, and ENSO intensity) on the relative abundance and composition of marine coastal assemblages, as well as their impact on the human populations and cultural changes should also be addressed in order to fully understand the magnitude of prehistoric harvesting on coastal ecosystems.

PRE-HUMAN DYNAMICS: TOWARDS A QUATERNARY BASELINE

Since the mollusc species pool of Quaternary fossil assemblages of northern Chile is virtually the same as modern assemblages (Rivadeneira and Marquet, 2007), Pleistocene and Holocene assemblages are the natural candidates for studying the natural dynamics of coastal ecosystems before humans arrived in the region. Over 150 years of Quaternary research in Chile has documented more than 100 mollusc species in 78 sites along the temperate Pacific coast of South America (Philippi, 1887; Ortlieb *et al.*, 1990, 1994, 1995, 1996, 1997a, 1997b; Paskoff *et al.*, 1995; Guzmán *et al.*, 2000; Rivadeneira and Marquet, 2007; Jerardino *et al.*, 2008; Rivadeneira and Carmona, 2008). However, despite the large degree of completeness of Quaternary mollusc fauna in the region (Rivadeneira and Marquet, 2007), its potential use as a 'baseline' to evaluate the magnitude of modern human impacts on coastal assemblages has largely been neglected.

Recently, Rivadeneira and Carmona (2008) have explored this idea. They showed that the species composition at a mid-Holocene and a last interglacial site (~80 000–125 000 years) in northern Chile was quite similar (Jaccard index of similarity = 0.88). Similar results have been reported in corals and Caribbean molluscs (Pandolfi, 1996; Gardiner, 2001; Pandolfi and Jackson, 2006), suggesting a large degree of inertia in the species composition (DiMichele *et al.*, 2004; McGill *et al.*, 2005) and it is consistent with relatively similar

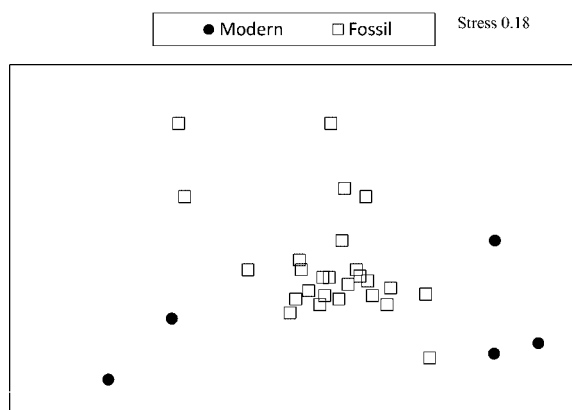


Figure 4. Ordination analysis (NMDS) comparing the species composition of five modern and 29 late Quaternary (last interglacial and Holocene combined) bivalve assemblages. Modern data taken from Laudien *et al.* (2007), Ramorino (1968), Rivadeneira and Carmona (2008), and Zuñiga *et al.* (1983).

sea surface temperatures between the last interglacial and Holocene (Calvo *et al.*, 2001; Molina-Cruz and Herguera, 2002). However, the composition in a modern local assemblage for the same locality studied by Rivadeneira and Carmona (2008) is dramatically different from that observed for the same site 80 000–125 000 years ago (Jaccard index of similarity = 0.24–41, after controlling for sampling bias), suggesting a marked and recent shift in the structure of marine coastal assemblages. In order to validate the idea of a recent shift in the structure of benthic assemblages, a new analysis was performed using five modern and 29 late Quaternary (last interglacial and Holocene) bivalve assemblages from northern Chile. The non-metric multidimensional scaling (NMDS) analysis showed again a striking difference between fossil (late Pleistocene and Holocene) and recent assemblages (Figure 4), and this difference was larger than expected by chance (ANOSIM, $R = 0.67$, $P < 0.0001$). In order to account for the inherent incompleteness of the fossil record, the analysis was repeated removing those modern species without a fossil record; however, differences remained significant (ANOSIM, $R = 0.52$, $P = 0.018$), supporting the robustness of the conclusions. Altogether, these analyses strongly suggest that the bivalve species composition of present-day assemblages is very different from that observed during the previous 125 000 years within the region. This adds further support to growing evidence showing a very recent human-induced shift in the structure and functioning of marine ecosystems around the globe (Jackson *et al.*, 2001; Jackson and Sala, 2001; Pandolfi *et al.*, 2003; Lotze *et al.*, 2006; Pandolfi and Jackson, 2006; Worm *et al.*, 2006). Whether this change was produced by overfishing or by modern human-driven oceanographic changes, or a mixture of both, remains to be resolved.

HUMAN IMPACTS ON COASTAL BIODIVERSITY: GETTING THE WHOLE PICTURE

When studied in isolation, the information gathered from fossil, archaeological, and contemporaneous marine assemblages says

little about the history of human impacts on coastal ecosystems. However, when all these records from different disciplines are combined, a new picture emerges, revealing key aspects of the coastal biodiversity across historical timescales (Jackson, 2001; Jackson *et al.*, 2001; Pandolfi *et al.*, 2003; Griffiths *et al.*, 2005). The analytical limitations imposed by the quality and/or incompleteness of the information could be overcome with additional work in fossil, archaeological and contemporaneous records. The outlined approach is by no means exclusive, and other sources of historical information (e.g. genetic and isotopic analyses, use of laminated sediments) could offer important insights. The combined potential of fossil, archaeological, and contemporaneous records would allow access to a ~125 000 year time window, crucial to test a series of questions and predictions. So far, the preliminary evidence presented herein suggests that overfishing may have produced a very recent (i.e. few decades to centuries ago), but major shift in the coastal biodiversity of Chile unseen in the last ~125 000 years in the region. However, the interactions between overfishing and human-driven climatic and oceanographic changes should also be addressed. These results could be used to establish a natural baseline to propose new, more specific, and more realistic achievable goals for management plans, and conservation policies.

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