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Spatial and Temporal Effects of Port Facilities Expansion on the Surface Area of Shallow Coral Reefs

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Abstract There is a close relationship between ports and reef areas, mainly because reefs provide protection to vessels against extreme weather events like storms and hurricanes. This historical relationship has generated severe impacts on reef ecosystems. In order to identify the main impacts from the construction of port facilities in shallow coral reef areas, we analyzed and described the effects of land reclamation and coastal structure construction associated to port growth throughout a century in the Sistema Arrecifal Veracruzano National Park, Mexico. We used aerial photographs and maps of the nineteenth and early twentieth century to assess the impacts caused by port expansion activities on shallow coral reefs. Three types of impacts were identified: (a) direct reef area loss caused by landfills and perpendicular coastal structures construction leading to the loss of nearly 50 % of the fringing reef near to the port; (b) fragmentation in short- and medium-term scale, which affects two fringing reefs, and (c) long-term modification of coastal dynamics leading to sedimentation and loss of a complete reef area. On the eve of a new expansion of Veracruz Port, we used the New Port Project Plan, long-shore net drift geomorphic indicators and the port impact typology from the 100-year period assessment to evaluate a possible future scenario. The scenario describes how the new expansion project will repeat the three types of impacts affecting a whole reef area, which is currently part of the National Park.

Keywords Port facilities · Reef area loss · Reef fragmentation · Marine protected areas

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Introduction

Ports are associated with several and different impacts on coastal zone environments such as beaches, sea grasses, and coral reefs. Shoreline activities including dredging, jetties development, and land reclamation have been reported as the principal sources of environmental degradation (Douven and others 2003; Cicin-Sain and Belfiore 2005). Throughout history growth of ports has changed the patterns of sediment transport and has modified shore currents due to the construction of coastal structures and landfills. These changes in coastal geomorphology (Cicin-Sain and Belfiore 2005) have also been associated with erosion/accretion rate changes (Frihy and others 2006).

Some of the main considerations to choose a location for a port are the wind and wave regimes (De Graauw 2000; Tsinker 2004). From this perspective, coastal areas protected by coral reefs represent important naturally protected places, which with the construction of additional protection structures become valuable safety areas against the forces of nature.

There are many ports in the tropical areas associated with fringing coral reefs, some examples are the Port of Sudan; Port of Djibouti, Massawa and Assab ports in Eritrea (Hassan and others 2002); Singapore Port; Hong Kong port in China (Chou 2006); and the Port of Veracruz in Mexico (Lerdo de Tejada 1850). In the future, population growth, urbanization, and associated industrialization will continue to propel sea-trade commodities which are handled via ports (Yap and Lam 2013). This will drive the expansion of actual ports and the construction of new ones.

Shallow coral reefs are highly sensitive to shoreline activities, especially to land reclamation. The physical damage caused by them is generally immediate and drastic (Erftemeijer and others 2012) with well identified sources, which are part of plans and projects that can be assessed.

The assessment of environmental externalities should be a cornerstone for port development projects. There are few studies around the world that assess the types of impacts on shallow coral reefs related with port developments. In this research, we aim to identify the types of impacts on shallow coral reefs caused by port expansions throughout a century and to describe their spatial and temporal occurrence. Also, we aim to use this typology to assess a new expansion project for the Port of Veracruz.

The Veracruz Port and Its Surroundings Coral Reefs

The current Veracruz Port, located in the Gulf of Mexico central part (Fig. 1), was established by Hernan Cortes since 1519. The port was set at its present location mainly in view of the fact that geographically, it represented a strategic advantage to avoid the attacks of the natives in the early years, and the pirates in later years. Coral reef structures provided protection for ships against the waves, hurricanes, and winter storms (Lerdo de Tejada 1850) and also materials for buildings construction (Heilprin 1890).

In the late nineteenth century (1895), after an important port modernization project, which included the gain of 100 ha of land over the neighboring shallow coral reefs and the construction of large coastal protection infrastructure (Blázquez 2000), Veracruz was established as the principal Mexican commercial port in the Gulf of Mexico.

The twentieth century brought new port expansion activities which included the construction of more coastal infrastructure and land gain activities. Nevertheless, in accordance with international commitments and a strong pressure by local actors, it was not until 1992 when the neighboring coral reefs were considered by the Mexican government as important to the operation and maintenance of Veracruz City and its Port. In that year, the coral reef zone was declared as the Sistema Arrecifal Veracruzano National Park (SAVNP) (Fig. 1). This national park consists of more than 52,000 ha, with 23 coral reefs structures, including six islands. Reef structures are divided into a northern and a southern group, which are divided by the inlet of the Jamapa River (Ortiz-Lozano and others 2009).

The northern group has four coastal fringing reefs. Three of them, Punta Gorda, La Gallega and Hornos are under the direct influence of port activities. Also, it has seven reef flats reaching depths of 25–30 m (Carricart-Ganivet and Horta-Puga 1993). These reefs form two natural channels,

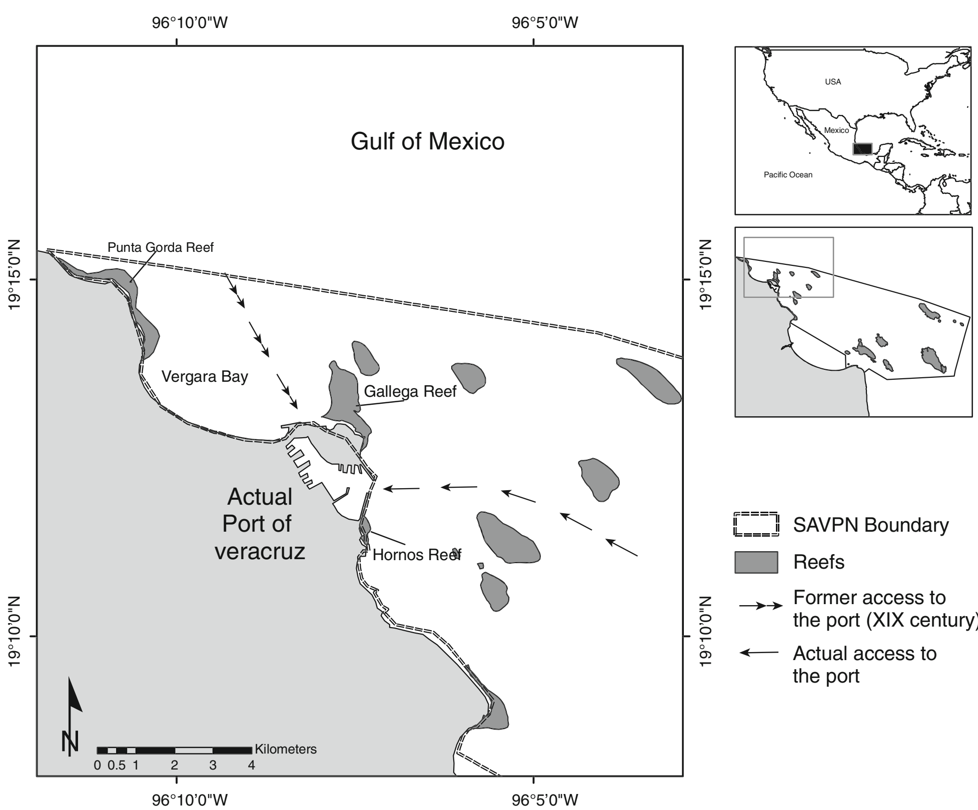

Fig. 1 Veracruz Port location. From sixteenth to nineteenth century, the main access of vessels to the port was across Vergara Bay. After the expansion of port facilities in the beginning of twentieth century, the main access was forced to run across the coral reef zone

which have been used for ship approach maneuvers (Lerdo de Tejada 1850). Only the southern channel is currently used as the approach route to have access to the port (Fig. 1).

The southern reefs group is located off shore Punta Anton Lizardo, approximately 20 km southeast of Veracruz, and it includes 12 reefs. All these reefs have well-developed structures with a well marked zonation (Carricart-Ganivet and Horta-Puga 1993), which is associated with the energy regimes that shape the benthic communities (Rangel-Avalos and others 2008). Reported diversity in all the reef areas includes up to 30 scleractinean coral species and 155 fish species (Rangel-Avalos and others 2008).

In the twenty-first century, on the initiative of the Natural Protected Areas National Commission (CONANP), the protection of the SAVNP becomes broader, due to the inscription of the natural area in the Ramsar's Convention list (2004) and in the Man and Biosphere UNESCO's program (in 2006). With this decision, the port of Veracruz became one of the few ports in the world in which vessel access is through a coral reef protected area.

Methods

To determine the effect of port growth on the surface area of shallow coral reefs, historical shoreline positions and coral reef surface were acquired from both vertical aerial photographs and historical maps. Vertical aerial photographs dated from 1946 to 1975 were georeferenced and disposed in mosaic (Coyne and others 1999) using the commercial software Arc Gis 9.3. Approximately, eight ground control points (GCPs) were selected per photograph using a 2007 georeferenced mosaic from Instituto Nacional de Geografia e Informática INEGI (2007). GCP's were located using permanent landmarks such as roads and old buildings; first-order polynomial transformation was applied to minimize the deformation of aerial photographs.

Because the middle part of a rectified image has better position accuracy than the edges, only the central third of each image was used when creating mosaics. The resulting mosaics were georeferenced images of a continuous stretch of coastline (Rooney and Fletcher 2000; Fletcher and others 2003).

There was no aerial photographic information of the Veracruz Port area at the beginning of the century to be found. A 1907 historical map was used to get the same stretch of coastline analyzed for this research. The map was georeferenced using the technique described previously.

In using historical aerial photographs and historical maps there are uncertainties related to map scale, verticality of aerial photographs, seasonal shoreline position and tidal stages (Rooney and Fletcher 2000; Yamano and others 2005). Mean error in each mosaic was determined during the geo-referencing process. 2007 mosaic was the base for georeferencing and considered with mean error 0. 1907, 1946, and 1975 mean mosaic errors are shown in Table 1.

It is clear that the georeferencing process can be affected by the influence of season and tide on the coast line shown in the images used, however, the goal of this research is to determine the trends of the human impacts on shallow coral reefs.

Coastlines for each mosaic and the 1907 map were digitized using photo-interpretation and the instantaneous water line (IWL) coastline concept (Leatherman 2003; Boak and Turner 2005). IWL was clearly distinguished in the resulting mosaics. This methodology is widely used and it is considered an effective way to delineate and analyze shoreline changes on scales of years to a century (Coyne and others 1999; Rooney and Fletcher 2000; Fletcher and others 2003).

Initial coral reef areas were determined by overlaying 1947 mosaic and 1907 georeferenced map to determine their seaward (from 1947 mosaic) and landward boundaries (from 1907 map). Coral reef areas were digitized using photo-interpretation (Palandro and others 2003; Yamano and others 2005). 1907 base reef polygons were obtained from this process and their area was determined. The same process was repeated for 1946, 1975, and 2007 mosaics.

1946, 1976, and 2007 coastlines were used to split the 1907 initial reef polygons generating layers of remaining coral reef areas for each period (1907–1946, 1946–1975, and 1975–2007). Area loss for three periods was obtained and percentage of loss in the period of analysis was calculated.

Fragmentation of coral reef areas for each period was calculated as well as the human activities related to port growth which caused it.

To determine the state of shallow coral reefs and the effect of port construction activities previous to the period of analysis and before the construction of the actual port of Veracruz, a map done by Captain Eads in 1882 (Conolly 1997) was analyzed. This map shows the stretch of coastline where the actual port is located and its neighboring

Table 1 Georeferenced mosaics mean error

	Mean error (m)
1907 Veracruz Port map	3.8
1946 mosaic	2.2
1976 mosaic	1.9

reefs (La Caleta and La Gallega). It was georeferenced and digitized using the same technique described for 1907 map.

We described a future scenario in the case of a new port expansion in the near future. We used the plan of the "New Port of Veracruz Project" (Silva-Casarin and Mendoza-Baldwin 2009) which is part of the Master Plan of Veracruz Port 2011–2016 (SCT–API 2011).

The New Port of Veracruz will include the construction of two major perpendicular coastal structures (4.4 and 3.6 km breakwaters), dredging works that go up to 4 million cubic meters, and more than 90 ha of landfills (SCT–API 2011), to be developed in the northernmost part of the SAVNP over a shallow reef area known as Punta Gorda. Punta Gorda is a fringing reef, which covers a 325.76 ha surface (DOF 1992) with not more than 12 m depth in the windward zone.

The Port of Veracruz expansion project was georeferenced, digitized and overlayed as the previous maps and aerial photographs. The future impacts of its construction on Punta Gorda and La Gallega reefs were determined by analyzing the implications of a new coastline configuration and its interaction with the actual near shore circulation (Salas-Pérez and others 2012) and long-shore transport models for the New port of Veracruz Project (Aleph 2009a, b; Silva-Casarin and Mendoza-Baldwin 2009).

Net shore drift direction in the New Veracruz Port project area prior and after the New Port of Veracruz project execution was determined using landforms as indicators of net shore drift direction within a littoral cell, particularly headlands (natural or artificial) and prograding beaches. We used the method described by Kunte and Wagle (1993). We established the geographical limits of the littoral cell where the New Port of Veracruz project will be constructed and considered the sediment source, littoral drift that moves sand along the shoreline and the sand sink (where sand is lost from the littoral cell) (Taggart and Schwartz 1988).

In the construction of the future scenario, we considered the similarities between Punta Gorda reef and the extinct La Caleta reef (Fig. 4), especially their position bordering the coastline as well as the similarities between the 1907 Port of Veracruz modernization Project and the 2009 New Port of Veracruz Project.

Results

Three human impacts affecting coral reef surface areas were identified (Table 2), which occur at different spatial and temporal scales. Type A: direct reef area loss caused by land-filling and perpendicular coastal structures construction; Type B: fragmentation operating in short-term scale and medium term scale, and Type C: long-term modification of coastal dynamics.

Table 2 Time and spatial scales of impacts originated by port expansion on coral reefs

Time	Spatial scale		
	Small scale	Meso scale	Large scale
Long term	–	C	C
Mid term	B	C	–
Short term	A, B	A, B	–

Type A impact is direct reef area loss caused by landfills and coastal structure construction. It operates spatially at small and meso-scales and short-term periods. Type B impact is fragmentation, which leads to a loss of connectivity operating at small and meso-scales in short- and mid-term periods and Type C impact is coastal dynamic modification, this type of impact operates at meso- and large-scales in mid- and long-term periods of time

Table 3 Loss of coral reef surface by period

Reef	Surface loss by period (ha)			Total loss (ha)	Total loss (%)
	1907–1946	1946–1975	1975–2007		
La Gallega	49.73	12.87	34.58	97.18	49.13
Lavandera	0.01	0.31	0	0.32	15.80
Hornos	0.11	4.04	2.66	6.70	12.38

Type A—Impact: Reef Area Loss

Major coastline modifications were identified in the period of analysis. The port of Veracruz gained large land areas over coral reefs in the 1946–1975 and 1975–2007 periods. Coral reef areas influenced by port expansion activities are shown in Table 3. La Gallega reef, the fringing reef closest to Veracruz Port, was the most affected. In the 100-year period of analysis it lost nearly 50 % of its surface (Table 3; Fig. 2). Coastal protection structures (large breakwaters) and landfills, mainly composed of construction debris and sand, substituted shallow coral reef surface area.

Hornos reef (Fig. 3) lost 12 % of its original area as a result of coastal protection structures construction and landfills.

The human pressures directly related with La Gallega reef loss and substitutions were port expansion projects. The continuous expansions were done to improve industrial shipping and port facilities. In the case of Hornos reef, land reclamation pressure came from tourism development.

The temporal scale of this type of impact in both La Gallega and Hornos reefs was immediate or short term (only during the material and sediment deposition works).

Type B—Impact: Fragmentation

The construction of coastal protection structures perpendicular to the coast, such as breakwaters, contributed not

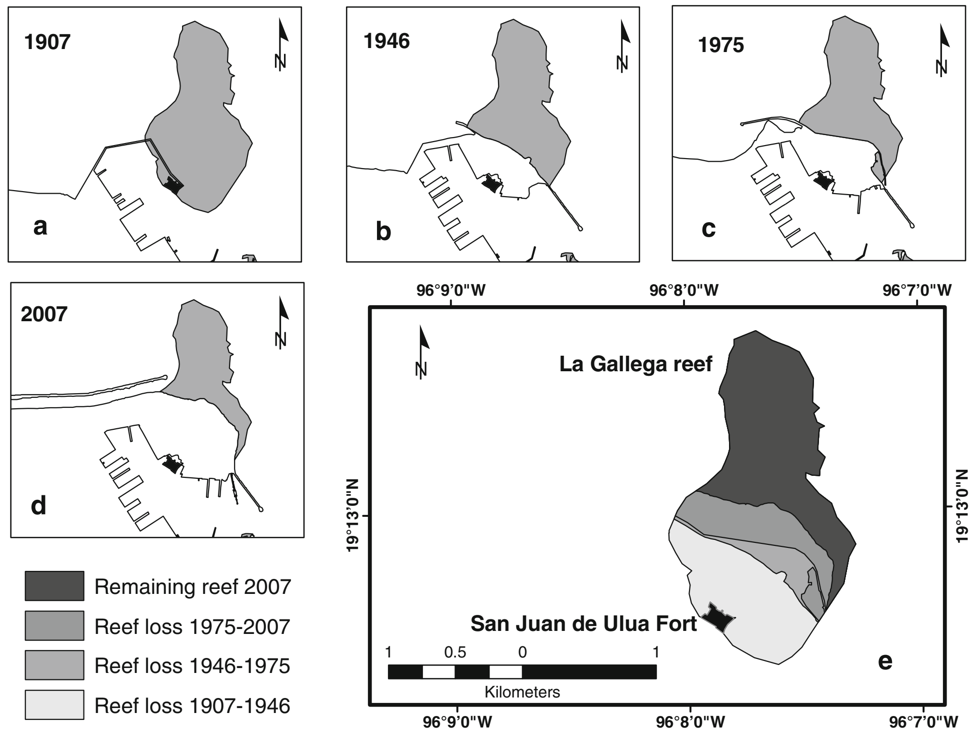

Fig. 2 Impacts on La Gallega reef surface area. **a**, **b**, **c**, and **d** correspond to the reef area of La Gallega in the years analyzed. **e** shows the cumulative area surface loss per period, caused by landfills (impact Type *A*, see main text)

only to the immediate and local loss of shallow reef surface (Type A impact), but also to fragmentation. When reef areas were very near the coastline these structures fragmented reef areas creating reef patches of different sizes. The temporal scale of patch creation was immediate. However, the medium-term effect of fragmentation and patch creation was the isolation of some of the patches. This may have limited water, organism, and energy fluxes between the patches.

Some of the shallow coral reefs assessed suffered both, the reef area loss and the creation of patches caused by coastal structures.

De la Lavandera, a small reef patch detached from the coast, suffered fragmentation and almost 16 % of area loss because of the construction and maintenance of a breakwater (Fig. 3; Table 3) in the period of analysis.

Hornos reef, a large fringing reef was fragmented in three parts because of the construction of perpendicular coastal structures and landfills (Fig. 3). One of the patches was isolated.

Type C—Impact: Long-Term Modification of Coastal Dynamics

The analysis of the 1882 Eads map showed that Veracruz Port is located and laid over a fringing reef which was known as “La Caleta.” This map, created for the modernization projects of Veracruz Port in the nineteenth century, shows clearly the coastline on 1882 and La Caleta reef which prior to port expansion was detached from the coast. The Eads map is one of the last cartographical evidences that this reef existed.

From this analysis, it was determined that La Caleta reef suffered from the three types of effects reported in this research (Fig. 4): (i) fragmentation caused by the closure of the Veracruz Port northern access channel, which led to the creation of two reef patches, one of them inside the new port facilities; (ii) reef area loss of the reef patch inside the port facilities caused by landfills and (iii) long-term effects caused by the modification of long-shore drift. The closure of the northern channel created a physical barrier which resulted in a high accretion zone which led to a slow but complete burial of La Caleta reef fragment (the fragment which remained outside the New Port).

Future Scenario

The New Port of Veracruz (2009) project area is located within a littoral cell that goes from the headland of Punta Gorda to the artificial headland created by the modernization of the Port of Veracruz in 1902. The input of sediments comes from the Antigua River located north from this littoral cell (Fig. 5a).

Since 1902, when the northern access to the Port of Veracruz was closed, a large sediment deposit area was created as a result of the continuous coastline modifications that affected long-term shoreline transport. We considered this accreting beach as an indicator of the long-term average net shore drift, which flows from north to south.

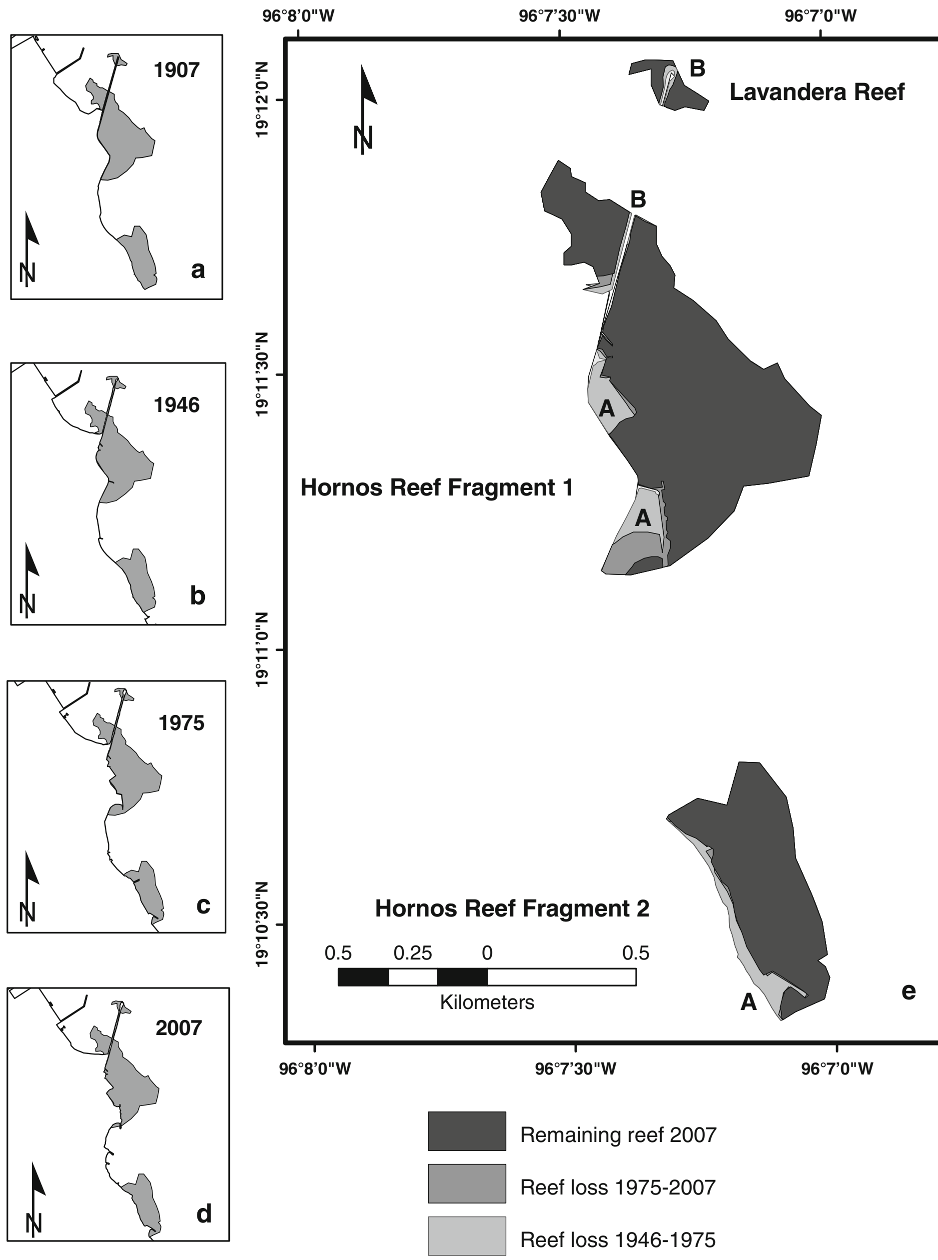

Fig. 3 Impacts on the reefs surface of Lavandera and Hornos. **a**, **b**, **c**, and **d** correspond to the reef area of Lavandera and Hornos in the years analyzed, which suffered Type *A* impacts (reef area loss trough landfill) and Type *B* impacts (fragmentation related to coastal structure construction). **e** shows the cumulative reef area loss per period in the la Lavandera and Hornos reefs over a century

The New Port of Veracruz project, which includes the construction of two breakwaters (of 4.4 and 3.6 km) and 90 ha of landfills, will result in a new coastline configuration that will cause Type A, B, and C impacts. The landfills proposed in the expansion project will cause the direct loss of 90 ha of Punta Gorda fringing reef (Type A impact) and will change coastline morphology in a short period of time (the duration of landfill works). The construction of major coastal protection structures, particularly the 4.4 km breakwater located in the northernmost part of the new port will cause the fragmentation of Punta Gorda reef, isolating the northern fragment (Type B impact).

Type A and B impacts will cause long-term modification of coastal dynamics (Type C impact) leading to new sedimentation patterns. Actually, the near shore current circulation carries sediments southward, from La Antigua River. Sediments are deposited on the beach located north from the actual Port (Fig. 5a). However, the physical barrier created by the construction of a 4.4 km breakwater to protect the New Port expansion will block the littoral transport and will lower the energy creating two new sedimentation areas (Fig. 5b): (i) one located exactly over the remaining patch of Punta Gorda reef, outside the port (in the long term, the remaining patch of Punta Gorda reef will be buried) and (ii) a second low energy sedimentation

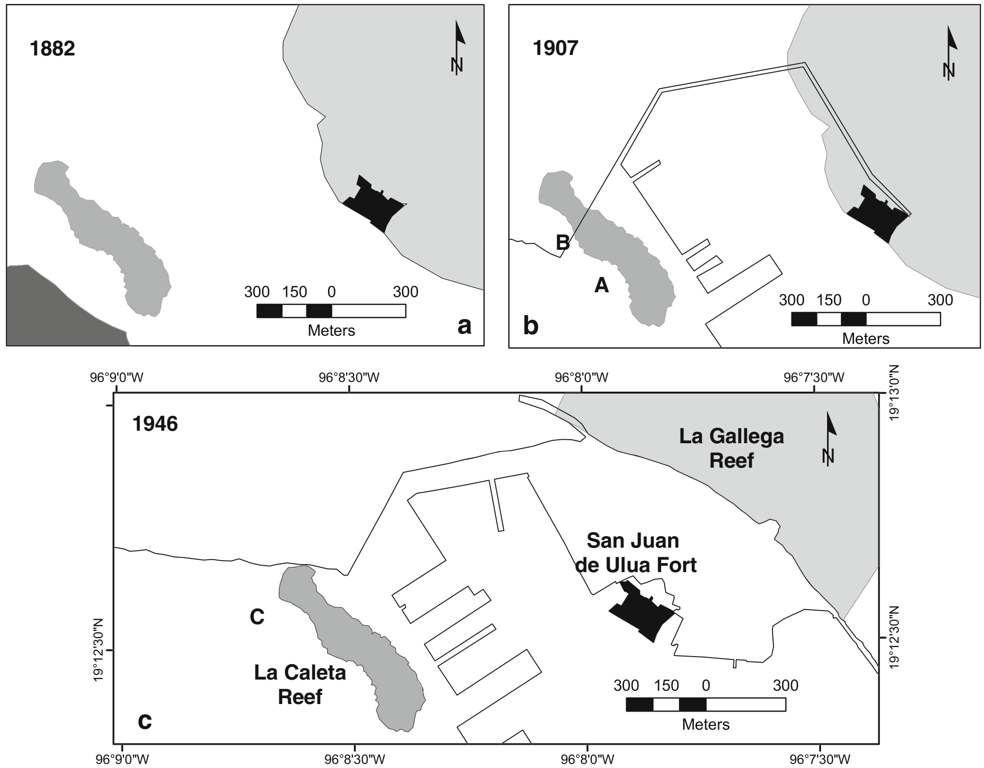

Fig. 4 La Caleta reef loss historical reconstruction. **a** shows La Caleta and La Gallega reefs in 1882 before the first great expansion of the Veracruz Port. **b** shows the location of Type *A* and Type *B* impacts, after the port expansion in early 1900. By 1946, La Caleta reef was completely covered with sediments

area will be created between the 3.6 km southern breakwater and La Gallega reef causing a permanent and stressful sediment rain over the remaining Gallega reef.

Discussion

Port Growth Historical Impacts on Shallow Coral Reefs

The economic importance of ports in terms of international trade has grown markedly, particularly in developing countries. Commercial, touristic, and industrial ports have become a vital component of global economy. The volume of seaborne trade has more than doubled in the past 30 years (Nicholls and others 2008) and will continue to grow by using any of the common strategies for port development: (1) restructuring existing spaces, (2) expanding to adjacent spaces, and (3) developing capacity in a new location (Yap and Lam 2013). In tropical zones, the expansion to adjacent spaces will probably compromise shallow marine environments such as coral reefs and sea grasses (PIANC 2010).

The Port of Veracruz represents an example of the type and extent of impacts related to port expansion projects. There are many similar cases in the tropical areas around the world that are under the same international pressures (Chou 2006; Hassan and others 2002).

In the last century, Veracruz port has developed major coastal projects to achieve efficient operation, which included dredging, land-filling, and coastal infrastructure construction activities. These have been reported as the major human activities generating degradation in corals and sea grasses (Maharaj 2001; Chou and Tun 2005; Guzmán and others 2008; Ortiz-Lozano 2012) and are considered the main causes responsible of negative long-term effects on sandy beach ecosystems (Defeo and others 2009).

Human-induced physical disturbances on coral reef habitats related with port development operate at different temporal and spatial scales (Chabanet and others 2005).

From the three impacts identified in the case of Veracruz port, the direct physical area loss (Type A impact), caused by removal or burial trough landfill, has been described before and it has been considered one of the key impacts on coral reefs related to port development (PIANC 2010). This impact has been reported in ports as Singapore, Okinawa, and Kagoshima in Asia (Nakano 2004; Chou 2006; Chou and Tun 2007).

In Singapore, the reef loss related to land reclamation programs was of over 50 % (Chou and Tun 2005; Glaser and others 1991). Burke and others (2002) estimated that prior to the land reclamation projects, at the end of the twentieth century; coral reefs covered an area of 100 km^2 and calculated a remaining one of 54 km^2. Dredging and reclamation activities continue in Singapore, thus affecting the remaining reef areas.

Other Asian ports in Okinawa have also suffered coral reef area loss related to land reclamation programs.

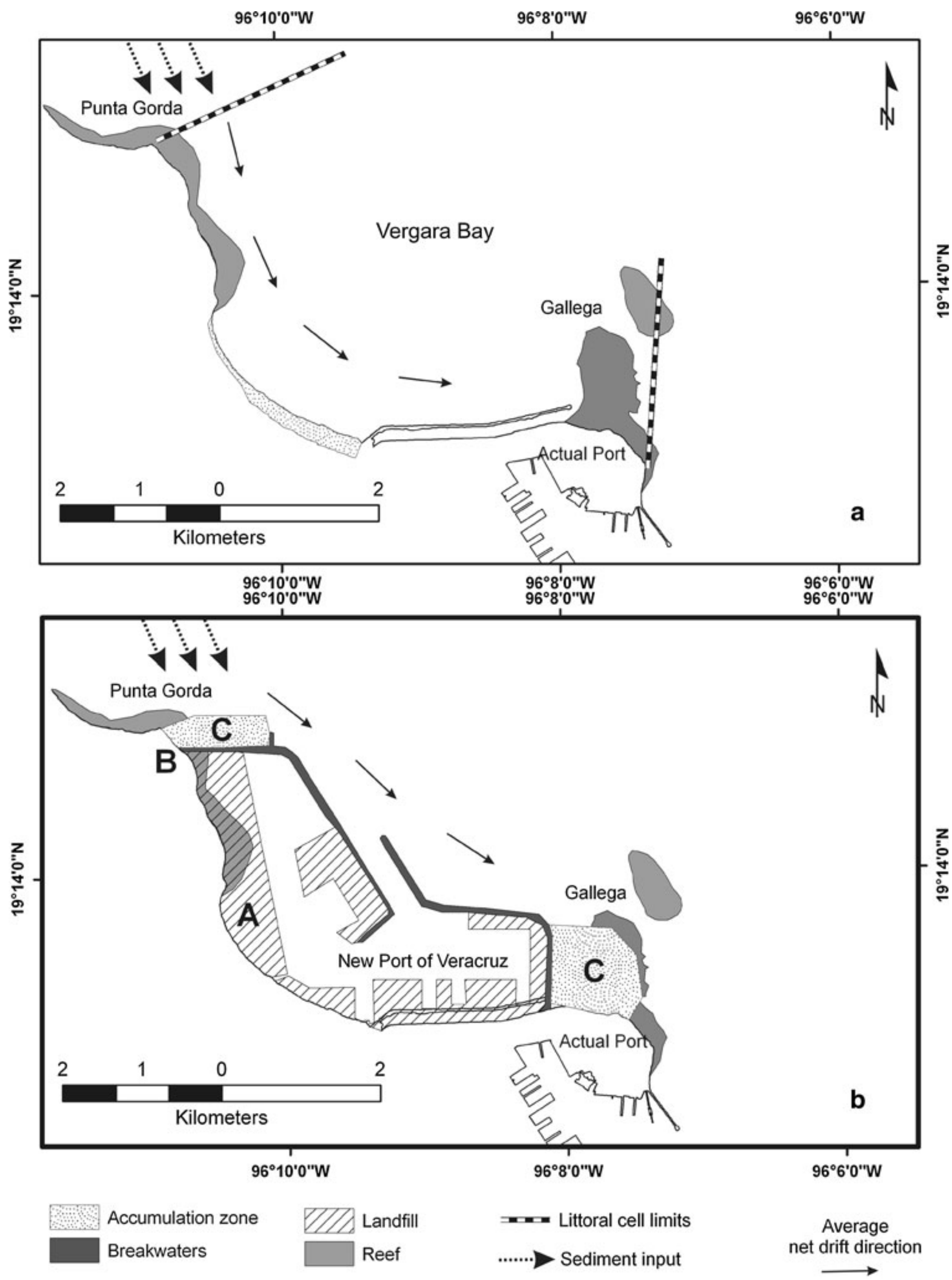

Fig. 5 The New Port of Veracruz project (2009): impact assessment scenario. **a** Actual long-shore net drift flow model, **b** modification to actual long-shore net drift flow pattern and the location of Type *A*, *B*, and *C* impacts on Punta Gorda and La Gallega fringing reefs after the construction of the New Veracruz Port project

Fujiwara (1994) reports a loss of 532 ha of coral reefs in 1982 in Nishisaki, and 49 ha in Kuwae, both in Okinawa Prefecture.

The immediate physical damage to coral reefs is directly related to excavation and landfill during the construction phase of expansion projects. Likewise, near shore dredging to obtain sand for landfills results in water quality changes and affects sedimentation rates (Erftemeijer and others 2012). Impacts of dredging on coral reefs, widely described by Erftemeijer, may result in coral mortality by burial and lethal or sub-lethal stress operating at short- or medium-term temporal scale.

The fragmentation of shallow reef areas (Type B impact) caused by the construction of coastal protection structures has a direct effect in the connectivity of marine environments which, in contrast with terrestrial ecosystems, is of greater importance (Carr and others 2003). Fragmentation affects the energy and material fluxes (PIANC 2010) isolating coral reef patches and leading to medium-term degradation or loss. This type of fragmentation has not been described before in peer reviewed papers as an impact of port expansion. Although it is likely that it has happened before in other ports in the tropical zones related to shallow coral reefs. Most of the literature associated to impacts of port expansion projects is found in the form of "gray literature," mainly as environmental impact assessments and consultancy technical reports written in local languages (Erftemeijer and others 2012). As an example, for the New Port of Veracruz Project, there are three available technical assessments, which include long-shore drift physical models (Aleph 2009a, b; Silva-Casarin and Mendoza-Baldwin 2009). Two of them, from private consultants and one from an engineering research institute.

In this research, fragmentation affected Hornos reef. It was fragmented in three patches by coastal protection structures and landfills during the last century. More recently (2010), one of the remaining patches was affected by the construction of the Marina "Veramar" and a commercial area, which included more landfills and coastal protection structures.

The long-term modification of coastline circulation caused by the construction of perpendicular coastal structures, related to port facilities and large scale reclamation programs, has been described before for beaches and shorelines. The blockage caused by the structures or landfills tends to generate an accumulation zone in one side of the structure and a deficit in littoral drift budget, related to lee side erosion, on the adjacent shoreline (Abbott 2013; Erftemeijer and others 2012; Benassai 2006).

Changes in coastal geomorphology may affect whole reef regions (Chabanet and others 2005; Cicin-Sain and Belfiore 2005; Frihy and others 2006) by inducing the modification of the physical conditions related to coral reef ecological dynamics. Water flow energy, sedimentation (Miles and others 2001; Hsu and others 2007; Erftemeijer and others 2012), and rates of illumination are the physical conditions that are closely related to coral reef connectivity. Their modification affects ecological processes such as larvae dispersal, recruitment, and survival (Bulleri and Chapman 2010), not only in reefs (Reigl and Branch 1995) but also on adjacent habitats (Bulleri and Chapman 2010) such as sea grasses (Erftemeijer and others 2012).

In this research, the major effect of long-term coastline circulation modification related to the construction of a large coastal structures and landfills for port expansion was the loss of a whole reef area (sensu Chabanet and others 2005). The case of La Caleta reef offers a detailed example of how a sequence of human activities with a seeming local and short-term impact, manifested to have a major impact when assessed in the long term.

Lessons from the Past for Future Planning

Looking to the past helps managers to assess the overall impact of their decisions and to make better plans for the future. By using historical remotely sensed data and long-shore net drift geomorphic indicators we identified the impacts of Veracruz Port expansion projects in the last century on shallow coral reefs. This knowledge, as well as the availability of the new large scale expansion project design for the port of Veracruz, enabled us to describe a future scenario based on a detailed spatial analysis rooted on the parallelisms found in the spatial location and general geomorphic characters of La Caleta and Punta Gorda fringing reefs.

The New Port of Veracruz, if constructed as it is planned, in combination with the local circulation, will cause the complete burial of a whole reef area, Punta Gorda. Thus, the case of "La Caleta" reef will be repeated with the difference that, until today, Punta Gorda reef is part of the SAVNP. And thus, it is bounded to important management decisions.

Beyond the possible impacts described in the future scenario for the case of Veracruz Port, it is of greater importance to highlight how, historical aerial photographic information, can be used to assess the overall impacts of port developments and port expansion projects in coastal areas, which are commonly related to shallow coral reefs. Historical aerial photographs capture coastline changes and these changes reflect the underlying coastal processes, which operate in the mid- and long-terms in local and regional spatial scale (Kunte and Wagle 1993).

It is common to find aerial photograph databases in developing countries. It is also common that there are few or no other historical available or reliable databases (Erftemeijer and others 2012). Furthermore, there are few or no economic resources to develop major monitoring programs to assess the impacts of port developments on coastal environments. Under this scope, aerial photographs are a rather cheap source of information.

There are few published studies on the effects of ports on coral reefs (Erftemeijer and others 2012). It is likely that international pressures will result in the growth of more ports (Yap and Lam 2013) associated with shallow coral reefs which are highly sensitive to coastline modifications.

This research provides a methodological framework and a typology to assess the impacts of port growth projects and new port developments around the world on shallow coral reefs. By using this approach, coastal resource managers may generate reliable and scientific soundly results in a relatively rapid and cheap manner.

Once identifying the type and magnitude of the impacts a particular project may have in time and space, the acknowledged allocation of resources, specific engineering and monitoring programs design, legal framework modifications or any other management decisions can be taken.

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