Coastal structures: mapping their distribution and determining their impact on the marine ecosystem

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Abstract
Artificial coastal structures such as jetties and sea walls can cause changes to the physical marine environment in many ways including providing new hard substrate for colonisation, shading, altering hydrodynamic processes and modifying nearby soft sediment grainsize. Many studies have also shown that artificial coastal structures have modified the surrounding marine ecological community causing changes in species distribution and abundance. But interactions between different types of structures, associated changes in physical processes and the resulting marine ecological patterns are complex and are generally poorly understood. Mapping the spatial distribution of different types of coastal structures categorised according to their physical characteristics is a first step towards understanding and predicting the effects structures are having on the marine environment.

As part of the Oceans 20/20 Coastal Survey, the distribution of artificial coastal structures from Spirits Bay to Bream head (on the north-eastern coast of the North Island of New Zealand) were mapped and described. A database was constructed using information from >1400 Northland Regional Council consents and a new classification system was developed that categorises structures based on their physical attributes (size, permeability, materials, angle, orientation, depth and shading). The study area was divided into zones and the distribution of each category among zones was described.

The Bay of Islands was clearly the most developed zone in the study region. It had many more structures than any other zone, was the only zone with all categories represented and had the greatest number of each category of structure, sometimes by an order of magnitude. This is likely due to the regions' resident population and its popularity as a holiday and tourist destination with its well developed local economy. Open coast zones without sheltered areas had the least number of structures and categories. The most common, and widespread, category was 'other', 85% of which are 'unidentified', generally because they are non-consented.

Structure distribution appears to be linked to population and economic drivers as well as the physical geography of the coastline. More information is being gathered by Northland Regional Council on coastal structures and it would be beneficial to maintain and update the database developed during this study.

Further research including surveys and field experiments as well as qualitative and quantitative modelling would give a better understanding of how structures interact with physical processes to affect marine ecosystems. Future work would provide guidelines on physical, biological and ecological structure effects to assist with marine coastal operation management decisions, consent applications and policy development. The marine environment would benefit through reduced risk of unplanned, unexpected or unknown changes to the marine ecosystem due to the placement of artificial coastal structures.

1 Introduction

Oceans 20/20 is a 15-year research programme initiated by the New Zealand government in 2005 to address the lack of knowledge required to protect and manage its ocean territory.

In order to determine the effects of human influence on the marine environment, and suggest management initiatives to assist in mitigating the adverse effects of human activities, a great deal of data is required. These data are needed to describe natural ecological patterns, and understand processes that maintain/change these patterns, in order to determine how human actions interact with these processes and hence affect ecosystem structure and function.

As part of the Oceans 20/20 programme a baseline review called The Bay of Islands Desktop Study was completed in March 2009. The study area encompassed the north-eastern coast of the North Island of New Zealand, from Spirits Bay in the north to Bream Head in the south including the Bay of Islands (Figure 1).

The purpose of the study was to collate data on the major physical and biological elements that make up the coast and shelf ecosystem. The study of the distribution of artificial coastal structures was part of that review.

The Northland coast has many embayments, rocky headlands, sandy bays, small islands and sheltered estuaries. The Bay of Islands is the largest and most complex of these embayments, which consists of a series of interconnected drowned river valleys, exposed headlands, protected beaches and estuaries and numerous islands and small islets.

Figure 1. The study area for The Bay of Islands Coastal survey is the north-eastern coast of the North Island of New Zealand.

Due to its spectacular natural character and cultural and historical significance, parts of the Northland coast, especially the Bay of Islands, have a high local population and are popular holiday and tourist destinations. This means some areas have been subject to a high level of coastal development, putting the marine environment under increasing pressure.

Many of the main attractions in the Bay of Islands require access by water, meaning a great number of artificial coastal structures (henceforth called “structures”) have been built for tourism such as jetties, pontoons and boardwalks. Structures have also been built to provide services for the local community (e.g., bridges, pipelines and cables), buildings (e.g., boathouses and clubrooms), coastal protection (e.g., seawalls and groynes) and recreation (e.g., boat ramps and marinas). Coastal structures also contribute to the economy through activities such as aquaculture (e.g., oyster farms). While coastal structures are a part of important positive economic growth, they can also have negative environment effects.

Marine habitats and their associated ecological communities are the products of local ecological, biological and physical processes. Coastal structures interact with these processes and depending on their scale, design and location these structures may have a significant impact on the local fauna and flora (Martin et al, 2005).

The location of a structure is important. For instance, the placement of a structure in a sensitive or unique patch of habitat will have a greater environmental impact than the placement of a structure in a large uniform, common habitat.

Each type of structure has different effects on the physical processes depending on its size and construction and will affect the local habitat in different ways. For example, a wharf has many vertical surfaces (usually made of wood or concrete) that will be semi-permeable to local hydrodynamics, with intertidal and subtidal areas and will shade out parts of the seafloor. In contrast a boatramp is an impermeable sloping concrete surface with no shade. The number of structures within a system also affects the impact on the marine environment. Multiple structures may have a compounding effect and place greater pressure on the marine environment (Martin et al, 2005).

The size of the system also influences the magnitude of impact a structure will have on the physical and ecological processes. A larger proportion of a small bay will be affected by a structure compared to the same structure in a larger system.

Policies on coastal structures are required to guide their number, size, design and placement in coastal environments and thus minimise their impacts. Yet in NZ there is a dearth of the information on coastal structure distribution and impact necessary to inform policy development and develop necessary regulations.

In this paper we describe the distribution of coastal structures in eastern Northland and discuss the effects of structures on physical and biological processes. Lastly, we suggest how these data could be better provided to planners in order to assist them to manage and protect the marine environment.

2 Methods

Various forms of data were provided by Northland Regional Council (NRC) for all recorded structures (consented and non-consented). These data were combined in a database that included structure coordinates, size, use and materials. Structures without coordinates were given estimated coordinates by entering general consent location information (e.g., Kerikeri inlet) into MapToaster (New Zealand Topographical Maps and Aerial Photography V4.00.194, Map Revision 3.0, Integrated Mapping.com). Although the coordinates yielded by MapToaster generally fell into the centre of the bay or inlet, this method was considered adequate as it is easily reproducible and the zones for the spatial distribution analysis were large, so exact coordinates were not essential.

In order to summarise the spatial distribution of different types of coastal structures, the following steps were taken: (1) classification of the structures into categories (2) definition of the zones within the study area and (3) counts made of the number of each category of structure per zone.

2.1 Structure classification

Structures were named and grouped at two levels. In order to retain detail within the database, the structures were first entered with the original names found on the consents. Many of these structures were very similar (e.g., seawall, rock walling and revetment) resulting in a total of 68 individual names.

In the second step, similar structures were considered according to physical attributes commonly referred to in the literature (size, permeability, materials, angle, orientation, depth and shading). Structures that had similar physical properties (and were therefore likely to have similar impacts on the marine ecological community) were grouped, resulting in a list of 12 categories (causeway, marina, marine farm, piles, pontoon, ramp/slipway, reclamation, seawall, small structure, structure on piles, wreck and other).

This meant some of the structures that were grouped together had different purposes but similar affects; for example, although berthing piles and navigation markers serve different purposes, they are both generally single wooden piles buried in the seabed and extending vertically into the water column with an intertidal and subtidal section and were therefore given the category of 'piles'. For the purposes of this study, the coastal structure data were spatially analysed at a level of 12 sub-categories.

2.2 Defining zones

The study area was divided into nine roughly equal sized zones (Figure 2) with similar boundaries to the zones used for other components of the Coastal Survey study (e.g., marine ecology). However the boundaries were extended towards the nearest headland or point in order to include the coastal harbours where coastal structures are usually found.

2.3 Analysis

GIS was used to determine the zone within which each structure was situated, and this information was added to the database for the distribution analysis. Microsoft Access was used to run the following queries on the database: (1) number of each category over the whole study area; (2) number of structures per zone; and, (3) number of each category per zone.

3 Results

Figure 2 is a map showing the distribution of all known structures according to category. Structures are generally found within sheltered harbours, with fewer structures along the exposed coasts. The density of structures is highest in the Bay of Islands.

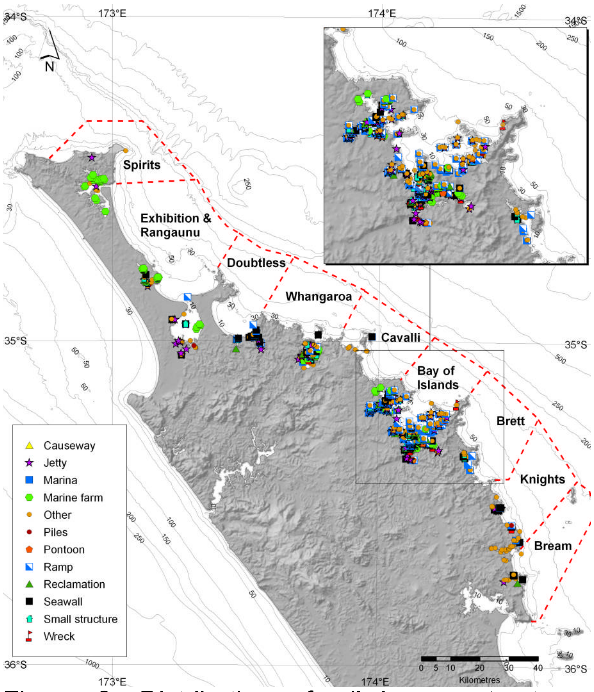

Figure 2. Distribution of all known structures according to category.

Table 1 shows the frequency of each category throughout the study area. The most common category was 'other', a large proportion (>85%) of which are 'unidentified', generally because they are non-consented. Structures on piles (e.g., jetties and buildings on piles), ramps/slipway), marine farms and seawalls were also common. The least common structures were causeways and wrecks.

Table 1. Frequency of each structure category throughout the study area.

Category	Frequency
causeway	1
wreck	7
marina	11
pontoon	28
reclamation	33
piles	46
small structure	72
seawall	108
marine farm	117
ramp/slipway	172
structure on piles	269
other	539

Table 2 shows the total number of structures per zone and the frequency of each category in each zone. The most structures occurred in the Bay of Islands zone (945), with all 12 structure categories represented. Open-coast zones without sheltered areas such as Spirits and Cavalli had the fewest structures (2 and 7 respectively) and structure categories (2 and 3 respectively). The remaining 6 zones had between 26 – 137 structures and 4 – 9 categories within sheltered harbours of varying size.

The frequency of each category is described next. The category 'other' occurs in all zones, with the most occurring in the Bay of Islands (342) followed by Exhibition and Rangaunu (49), and Whangaroa (47).

Jetties and other buildings/structures on piles were widespread, occurring in all zones except Cavalli. Most of these are found in the Bay of Islands area (205), followed by Exhibition, Doubtless and Whangaroa with ≤19, while other zones had ≤6.

Seawalls/retaining walls are widespread, occurring in all zones except Spirits, but they are most common in Bay of Islands (49), Knights (28), and Doubtless (14), with ≤5 in the other zones.

Ramps and slipways occur in all zones except Spirits and Bream. There are many more ramps in the Bay of Islands (132) than elsewhere with the next highest number being 12 in the Doubtless zone, <10 in Whangaroa and Knights and ≤5 in the other zones.

Reclamations/infilling are wide-spread, occurring in all zones except Spirits, Cavalli and Brett, but are generally found in small numbers (<5) except in the Bay of Islands (21).

Small structures are less common, occurring in 5 zones with the most in the Bay of Islands (58) followed by Exhibition <10. Doubtless, Whangaroa and Brett have <5. Single piles are also less common, occurring in the Bay of Islands (33), Exhibition (7), and Doubtless and Knights (<5).

Marine farms appear in 3 zones with the most in the Bay of Islands (59) and the far north zones of Exhibition and Whangaroa.

Marinas occur in low numbers (<5) in Whangaroa, Bay of Islands and Tutukaka.

Pontoons are common in the Bay of Islands (28) and only occur in that zone.

Table 2. Total number of structures per zone and the frequency of each category in each zone.

Zone	Total number of structures	Category	Frequency
Spirits	2	structure on piles	1
		other	1
Exhibition & Rangaunu	137	structure on piles	19
		marine farm	45
		other	49
		piles	7
		ramp/slipway	2
		reclamation	4
		seawall	4
		small structure	7
Doubtless	62	structure on piles	18
		other	12
		piles	2
		ramp/slipway	12
		reclamation	3
		seawall	14
		small structure	1
Whangaroa	100	structure on piles	18
		marina	4
		marine farm	13
		other	47
		ramp/slipway	6
		reclamation	3
		seawall	4
		small structure	4
		wreck	1
Cavalli	7	other	5
		ramp/slipway	1
		seawall	1
Bay of Islands	945	causeway	1
		structure on piles	205
		marina	5
		marine farm	59
		other	342
		piles	33
		pontoon	28
		ramp/slipway	139
		reclamation	21
		seawall	49
		small structure	58
		wreck	5
Brett	26	structure on piles	1
		other	15
		ramp/slipway	5
		seawall	3
		small structure	2
Knights	84	structure on piles	6
		marina	2
		other	35
		piles	4
		ramp/slipway	7
		reclamation	1
		seawall	28
		wreck	1
Bream	40	structure on piles	1
		other	33
		reclamation	1
		seawall	5

Wrecks are uncommon with five occurring in the Bay of Islands (in some cases these are derelict buildings/jetties) and the other two occurring in Whangaroa and Knights.

Only one causeway exists in the study area, which is found in the Bay of Islands.

There are few data about the location or type of many non-consented structures. Some are historical such as the 19th century stone seawall fronting the Stone Store in the Kerikeri basin. Many more, however, are illegal structures for which there currently is no formal information (Ricky Eyre, pers.com). These structures are not able therefore, to be represented in this study.

4 Discussion

Population and associated economic activity generally explain structure distribution. For instance:

- The Bay of Islands had the most structures and categories (expanded below).
- A high proportion of structures in the far north Exhibition zone are marine farms. This could be because there is a lower human population in this area and thus less impact on the environment resulting in higher water quality, more suitable for marine farms. Additionally, there are fewer people to oppose new marine farm proposals.
- Many seawalls occur in the Knights zone; almost all at Whananaki. A web search shows this coincides with intense local development and subdivision.
- Only two structures occur in the Spirits zone which is a very low population area. Department of Conservation information indicates the adjacent land is mostly recreational reserve and Maori land.

The Bay of Islands was clearly the most developed zone in the study region. It had seven times more structures per zone than any other zone, it was the only zone with all 12 categories represented and it had the greatest number of each category of structure, sometimes by an order of magnitude. This is likely due to the regions' resident population and its popularity as a holiday and tourist destination with its well developed local economy, resulting in pockets of highly developed shoreline in the many protected harbours, bays and islands.

Physical reasons may also explain distribution patterns as open coast zones without sheltered areas (Cavalli and Spirits) had the least number of structures and categories.

Many structures are unidentified which makes it hard to determine what is driving the distribution as the structures type is unknown.

There are many illegal coastal structures in the Northland region that are not yet accounted for and thus missing from this distribution study. However, NRC is currently working on improving coastal structure monitoring in Northland and expects that within three years all illegal structures will be accounted for (Ricky Eyre, pers.com). The database will provide some useful information on the type and distribution of structures. Future benefits will be realised by maintaining and enhancing the database as structures are added or documented. The database will provide policy makers and regional planners and managers, as well as consent authorities, with accurate and relevant information on structure distribution necessary to make informed decisions.

NRC Coastal Plan ecological assessment criteria for structures currently require consideration of effects on biodiversity, biological productivity, fish migration, abundance and distribution of plants and animals, vegetation (e.g., saltmash, seagrass, mangroves) and damage/modification to indigenous fauna (Regional Coastal Plan for Northland, 2004).

Policies exist for assessing ecological impacts but implementation seems to be subjective and lacks data and guidelines. Examples of these problems include:

- Emphasis on the visual impact of structures.
- Data for small applications (e.g., jetties) are usually in the form of photographs of the proposed site.
- There is a lack of data on existing biodiversity and ecological patterns.
- There are no data on how structures interact with physical coastal processes.
- There are no data on the effects of existing structures on the ecosystem.
- Structures such as jetties are currently assumed to have a small footprint on the seafloor relative to the surrounding marine area and effects are assumed to be negligible.
- There is no process for assessing how multiple structures are affecting local ecosystems or physical processes.
- There are no guidelines for determining the effect of additional structures.

These problems are largely due to a lack of available data, and to a lesser extent to methods of assessment. While some of the baseline data will be provided by the Oceans 20/20 survey, interpretive approaches need to be made available to decision makers though conceptual models or guidelines.

Larger structures such as marine farms are known to have a more severe impact on the environment and a great deal more assessment is required during the consent process. This includes data collection and analysis, and often, hydrodynamic modelling. Ongoing monitoring is often also required.

This kind of approach for small and medium size structures collectively would greatly benefit the marine environment as these structures may also have a cumulative effect on local habitat and ecology.

Natural ecological patterns (such as biodiversity, species distribution and abundance; community structure and function) are determined by the biological and ecological processes of recruitment, settlement, productivity, predation, competition and reproduction. Physical processes such as the hydrodynamics and grainsize also play a part in determining natural ecological patterns, by influencing habitat characteristics. Certain species have characteristics that allow them to flourish in habitats that have certain levels of tidal flow, wave exposure, sediment grainsize, shore height, depth, substrate type or roughness and light among other things.

Structures change habitat parameters by disrupting some physical processes including hydrodynamics such as wave activity and tidal flows (Martin et al 2005; Holloway and Connell 2002) which can cause changes in bed friction and turbulence on and around hard substrates (Wilhelmsson and Malm 2008) and disturbance to surrounding soft sediment grainsize (Martin et al 2005; Vaselli et al 2008).

Structures also change habitat properties by introducing a new hard substrate for colonisation by plants and animals. But structures may differ in orientation (to shore and/or the flow), depth (if there are no natural subtidal reefs), angle or slope (in relation to the seafloor) and surface composition (material, roughness or topography) compared to nearby natural substrates (Clynick et al 2008; Chapman and Bulleri 2003). Some structures such as wharves also provide large areas of permanent shade (Blockley 2007; Glasby 1999)

Changes to biological or ecological processes where structures are present have included modification to species diversity and/or abundance compared to the species found on local natural hard or soft substrates and habitat fragmentation (Connell 2001; Clynick et al 2008; Blockley 2007; Lindegarth 2001; Bulleri 2005; Moschella et al 2005).

Structures can support a subset of natural assemblages, or provide habitat for additional species not normally locally found (Chapman and Bulleri 2003) and are often inhabited by invasive species (Vaselli et al 2008; Tyrrell and Byers 2007).

When structures are built along shores that have no natural hard substrate they can increase the connectivity of reef associated populations. This can increase the geographical range of natural and invasive species, causing them to spread more easily (Airoldi et al 2005).

But some effects due to structures could be considered positive such as the addition of artificial reefs in an area with no natural subtidal hard substrate. In this case the substrate encourages encrusting fauna and flora (Martin et al 2005) that can be explored by recreational SCUBA divers thus enhancing economic opportunities.

The classification system described in this paper is a work in progress and hasn't yet been tested. Although changes to ecological patterns around structures have often been observed, exactly how physical processes contribute to these changes is often unknown. The next step is to generate a qualitative model to determine the direction of impact (positive or negative) and generate hypotheses about effects of certain structures on certain groups of ecological groups (*sensu* Airoldi et al, 2005).

Further research could include measurements of physical processes (flows due to tides and waves, properties of soft and hard substrates, light, suspended sediment concentrations) around unmodified ecological communities. These would be compared to measurements around coastal structures in order to quantify how particular physical processes are affected by coastal structures. In addition, the impact of the twelve different coastal structure categories on local ecological communities would be quantified. This could include the assessment of non-indigenous species present on the structures.

A quantitative model that includes hydrodynamics, sediment transport and an ecological database could then be developed. This could facilitate the assessment of the impact of size, permeability, materials, angle, orientation, water depth and shading of the structure on the physical and ecological processes and biodiversity patterns as well as any biosecurity risks.

The guidelines developed from the models could be used to estimate (1) the impact of existing structures on the marine system, and (2) how additional structures may affect those systems. This will assist planners in deciding whether a structure should be built, or existing structures remain.

The marine environment will benefit through reduced risk of unplanned, unexpected or unknown changes to the marine habitat (physical or biological processes) due to the placement of artificial coastal structures. Modification of systems (bays, harbours, estuaries) that already have structures in place will be better understood, and the possible effects of additional structures can be considered prior to the structure being built. This would help to protect marine community structure and function.

5 Summary

Ecological responses to physical changes caused by structures are often complex. In order to understand how structures are changing physical processes and ecological patterns, a great deal of information is required. Describing the distribution of structures is a first step towards understanding how structures put pressure on marine ecological processes. A better understanding of these processes will assist management with policy and implementation.

Outputs and guidelines from this work would assist Regional Council staff to assess, plan and manage placement and design of coastal structures in order to lessen physical impacts on the marine habitat and thus the ecology.

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