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# Wave modelling as a proxy for seagrass ecological modelling: Comparing fetch and process-based predictions for a bay and reef lagoon

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ABSTRACT

The distribution, abundance, behaviour, and morphology of marine species is affected by spatial variability in the wave environment. Maps of wave metrics (e.g. significant wave height $H_s$, peak energy wave period $T_p$, and benthic wave orbital velocity $U_{RMS}$) are therefore useful for predictive ecological models of marine species and ecosystems. A number of techniques are available to generate maps of wave metrics, with varying levels of complexity in terms of input data requirements, operator knowledge, and computation time. Relatively simple “fetch-based” models are generated using geographic information system (GIS) layers of bathymetry and dominant wind speed and direction. More complex, but computationally expensive, “process-based” models are generated using numerical models such as the Simulating Waves Nearshore (SWAN) model. We generated maps of wave metrics based on both fetch-based and process-based models and asked whether predictive performance in models of benthic marine habitats differed. Predictive models of seagrass distribution for Moreton Bay, Southeast Queensland, and Lizard Island, Great Barrier Reef, Australia, were generated using maps based on each type of wave model. For Lizard Island, performance of the process-based wave maps was significantly better for describing the presence of seagrass, based on $H_s$, $T_p$, and $U_{RMS}$. Conversely, for the predictive model of seagrass in Moreton Bay, based on benthic light availability and $H_s$, there was no difference in performance using the maps of the different wave metrics. For predictive models where wave metrics are the dominant factor determining ecological processes it is recommended that process-based models be used. Our results suggest that for models where wave metrics provide secondarily useful information, either fetch- or process-based models may be equally useful.



## 1. Introduction

Spatial gradients in the height and energy of waves drive the distribution, morphology, and functioning of many marine species and ecosystems (reviewed in Barry and Dayton, 1991). For instance, particular species of plants and animals are only found in low wave energy environments, whereas others are only found on exposed shorelines – leading to a shift in community assemblage across spatial gradients in physical oceanographic setting (Burrows et al., 2008). Predictive models of species occurrence may therefore be formed based on maps of gradients in wave parameters (Burrows et al., 2008; Garcon et al., 2010; Chollett and Mumby, 2012; Saunders et al., 2014). Predicted changes in wave height from sea-level rise (Sheppard et al., 2005; Storlazzi et al., 2011; Saunders et al., 2014) and altered intensity of tropical storms (Elsner et al., 2008) will likely change the distribution of shallow coastal marine organisms and habitats, some of which form the basis of livelihoods and food supply. Maps of wave metrics are required to predict their present and future distributions.

Ecologists working with limited budgets have often used improvised solutions for measuring relative flow in the marine environment. Oceanographic instruments used to measure wave parameters tend to be expensive (e.g. wave rider buoys at tens of thousands of dollars and pressure sensors around thousand dollars)

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and therefore cannot typically be deployed at all sites of interest within a study region. For example, plaster of paris cubes of known mass can be deployed and retrieved for low cost, with the inference that higher dissolution of the plaster indicates higher relative water flow (either tidal, wind or wave driven, Muus, 1968). These data reveal only relative information about water flow, and are dependent on other environmental conditions, such as temperature. Estimates of wave force may be made by deploying wave force dynamometers, which record continuously (Denny, 1988) or provide an estimate of maximum wave force over the deployment period (e.g., Helmuth and Denny, 2003). These low cost methods undoubtedly provide important information about the wave conditions in the marine environments, yet they do not provide data which are easily comparable to other studies. Moreover, generating maps of wave parameters from such point based measurements of wave height or relative water flow is challenging. With increased interest in development of spatial data sets used in predictive models of species occurrence or abundance comes the need to develop robust and transferrable methodologies for generating wave metrics maps.

There are several methods available for generating maps of wave conditions (e.g., Sundblad et al., 2014). The simplest, known as the exposure index, involves calculating the fetch (distance of ocean uninterrupted by land) at particular points of interest on the coastline (CERC, 1977). The only data requirement for this method is a nautical chart of the coastline. Increased information may be included by factoring in wind strength and direction (e.g., Ekebom et al., 2003; Chollett and Mumby, 2012). These simple fetch based maps can be useful for predicting species occurrence (Ekebom et al., 2003; Burrows et al., 2008), yet are only applicable to coastlines so are only useful for predicting distribution of intertidal (between the high and low tide) organisms. By including bathymetric data (e.g., Hill et al., 2010), indices of wave height, period, and benthic wave orbital velocity may be generated from fetch-based models (e.g., van der Wal et al., 2008; Rohweder et al., 2012; Sundblad et al., 2014). Beyond fetch-based approaches, engineers and oceanographers typically run mechanistic wave models, which factor in wave growth, nonlinear wave propagation in deep water, and shallow water propagation (refraction, diffraction, friction, depth limited wave breaking) with Holthuijsen (2007) providing an up-to-date treatment of this topic. Output from such models have been used to predict species distributions for sub-tidal organisms, such as seagrass (Saunders et al., 2013, 2014) and have been shown superior to fetch-based models (Callaghan et al., 2010). Such models are transferrable and much more realistic, yet have higher data, computing and expertise requirements.

Given the range of techniques available to generate maps of wave exposure or wave metrics, and the interest in using these metrics to predict the present and future distribution of marine species and habitats, it is timely to determine how the performance of each model output type in predictive ecological modelling balances against the costs (data, computing time, expertise) involved in generating each type of map. Previous work on this subject was conducted by Sundblad et al. (2014), who compared the performance of wave models of various levels of complexity on their performance for predicting ecological communities occurring on rocky shorelines on the west coast of Norway. How various wave model types perform for subtidal (below the low tide level) species, is unclear. Hill et al., 2010 undertook similar fetch based modelling around Tasmania, Australia. Their coastlines were approximately uniform longshore (for spatial scales relevant to waves) and consequentially, spatial gradients of arriving wave metrics are significantly more important than spatial gradients introduced via shallow water mechanics (i.e., fetch-based models are good at estimating arriving wave metrics before shallow water effects have an impact). This approximately uniform feature is absence in some bays and lagoons for their wave climates.

The aim of this paper was to compare patterns in wave metrics determined by two different wave modelling techniques, and to quantify how well each data set predicted the distribution of subtidal marine habitats. To do so, we: 1) generated maps of significant wave height $H_s$, wave period $T_p$, and benthic wave orbital velocity $U_{RMS}$, using both fetch-based and process-based models; and 2) compared the predictive performance of the outputs from the two wave models for determining the presence or absence of shallow water seagrass communities, using a probabilistic species distribution model. The study was conducted at two sites on the east coast of Australia – Lizard Island, Great Barrier Reef, and Moreton Bay, Southeast Queensland. Results based on the process-based wave model outputs have been previously published (Saunders et al., 2013, 2014), where we refer the reader for further information related to the statistical methods. Callaghan et al. (2010) provided the detail methodology used to implement the process-based wave model used here. Based on the results we provide guidance to those seeking to determine the most relevant methodology for generating wave maps for use in distribution modelling.

## 2. Methods

We compare fetch and process-based wave model predictions for ecological studies (e.g., habitat studies), using Moreton Bay and Lizard Island lagoon (see Fig. 1) case studies. Moreton Bay, formed by mainland Australia, Moreton and North Stradbroke Islands, has spatially varied exposure to ocean swell. The wave climate at the northern extent (near Bribie Island), which is exposed to the Coral Sea (and Pacific Ocean) is a complex combination of ocean swell and locally generated wind-waves, often propagating in different directions (Fisk et al., 2012). Further within the bay, waves are locally generated by wind (e.g., see assessment by Patterson, 2000 near the airport). Lizard Island is sheltered from Pacific Ocean swell by the Great Barrier Reef outer reef rim, the closest part being approximately 20 km to the north-east of this island (Fig. 1). This sheltering extents to northerly through to south-easterly directed waves with other directions being blocked by multiple coral reefs within the lagoon (Fig. 1). Hardy et al. (2001) concluded similar sheltering effects for most areas within the Great Barrier Reef lagoon (their Fig. 1). As a consequent, Lizard Island lagoon is exposed to locally generated wind-waves primarily from the Great Barrier Reef lagoon.

### 2.1. Wave parameters

Wave parameters used in habitat and other ecological modelling often include significant wave height, peak wave period, peak wave direction, wave energy density, benthic velocities, bed shear stress and drag forces. These quantities are easily obtained from either fetch- or process-based wave models either directly or from post-processing. However, it is unclear what measures of wave height, benthic velocity, wave period and fluid forces must be used. While there may be conclusive answers for these questions for physical processes, a more open ended approach is often used when building a probabilistic habitat model where mechanisms are unknown and interactions modelled stochastically.

The wave parameters selected for the present study were significant wave height, $H_s$ peak wave period, $T_p$ and peak wave orbital velocity, $u_p(z)$ based on $H_{\mathrm{RMS}}$, $T_p$ and mean water depth $h$. As we are investigating physical–biological interactions where the biological processes are significantly more complex than that of the physical system, the first simplification we adopted is the use of linear wave theory, which is based on the sine shape (Airy, 1841), with more complex wave theories (see for example, Fenton, 1990) ignored on