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An ecosystem model of the Prince Edward Island archipelago

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ABSTRACT

A model of an ecosystem provides a useful tool for the exploration of management options to achieve desired objectives. With the move to a more holistic approach to marine resource management, ecosystem models and the indicators that can be derived using them, are providing a means to move away from single species management and allow for the ecosystem effects of population dynamics to be explored. This work describes the construction of an ecosystem model of the Prince Edward archipelago. The archipelago consists of two islands, Marion and Prince Edward, which are situated southeast of the southern tip of Africa at 46°46′S, 37°51′E. The islands are host to millions of seabirds and seals that use the islands as a refuge for breeding and moulting. Using the Ecopath software, the ecosystem is described across three separate decades (1960s, 1980s, 2000s). All trophic links are described based on the rich published literature that exists for the islands. Local survey data for population estimates and trophic linkages were sourced for defining and quantifying the food web. The system is summarised into 37 functional groups which include 4 primary producer groups at the lower trophic spectrum, and 14 land based top predator groups (seals and seabirds) representing the majority of the higher trophic levels. Two detrital groups are included. The food web is compared across the three time periods with transfer efficiencies declining for the higher trophic levels through time, suggesting a decline in energetic coupling between groups. Comparison of the PEI ecosystem with eight other modeled sub Antarctic/Antarctic systems showed the ecosystem size (as measured in total biomass throughput per year, year^{-1}) to be lower than all other systems and was found to be most similar to the Kerguelen Islands for the ecological metrics assessed. Future research priorities are highlighted based on an assessment of data availability, data gaps and sensitivity testing. The construction of this model provides a much needed tool for the advancement of management for the archipelago, which have both fisheries and conservation concerns.

1. Introduction

The Prince Edward Islands (PEIs), like all Sub-Antarctic islands are hotspots of biological activity (Pakhomov and Chown, 2003). The combination of the alteration of oceanographic dynamics by the interception of an island system and the provision of substrate for both land based top predators and benthic organisms combines to provide a site of elevated productivity in an otherwise relatively low productivity region. These islands are host to millions of seabirds and seals that use the islands as a seasonal breeding ground and refuge during moulting (Ryan and Bester, 2008). The shelf areas around the islands are known to support increased levels of benthos and fish populations which aid in supporting the seasonal residents.

At the PEIs the population dynamics of many of the seabirds and seals has been well documented over the past 60 years. Disparate trends have been observed. In some instances the changes can be linked to known drivers. For instance, the Sub-Antarctic Fur Seals (*Arctocephalus tropicalis*) population increased exponentially from a few hundred individuals in the 1950s to over 150,000 by 2010 (Bester et al., 2009; Condy, 1981; Hofmeyr et al., 1997, 2006; Kerley, 1983; Wilkinson and Bester, 1990a), which is believed to be a population recovery following past exploitation. In other instances the changes, while studied, are not well understood. The Southern Elephant Seals (*Mirounga leonina*) have been in decline at the islands since the 1970s (Bester and Hofmeyr, 2005; Condy, 1977, 1978, 1981) with no conclusive understanding of the reasons behind the decline, though interspecific competition, competition with fisheries and environmental changes have all been cited for this species globally (Goldsworthy et al., 2001; Green et al., 1998; McMahon et al., 2005;

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Wilkinson and Bester, 1990b). Population fluctuations for penguin species have also been shown with the Southern Rockhopper Penguins (*Eudyptes chrysocome filholi*) and the Macaroni Penguins (*Eudyptes chrysolophus*) experiencing significant declines between 1994/1995 and 2008/2009 of 70% and 30%, respectively at the PEIs, (Crawford et al., 2009) raising conservation concerns.

Along with the land based top predators, the only fish species to be targeted by a fishery has also experienced a collapse in the population. The Patagonian toothfish (*Dissostichus eleginoides*) has diminished to a fraction of its former population status following unsustainable catches being harvested from a pristine stock (largely taken illegally in the initial phase of the fishery in the 1990s) (Brandao and Butterworth, 2009; Brandao et al., 2002; CCAMLR, 2011). Fishery related by-catch of seabirds is documented as resulting in population related fluctuations for some of the albatross species (e.g., Wandering Albatross, *Diomedea exulans*) that breed at the islands (Nel et al., 2002a,b, 2003) though mitigation measures have been successful in reducing these events (CCAMLR, 2011). Still, conservation concerns at the islands have been highlighted as all five of the populations of albatross that breed at the islands have been classified as having special status ('near-threatened, vulnerable or endangered') by BirdLife International (2014) (IUCN Red List for birds. Downloaded from http://www.birdlife.org on 24/04/2014).

With the islands therefore having both fishery (related to the past seal fishery and current toothfish fishery) and conservation concerns (where population declines have been documented for apex predators with conservation status that identifies them as threatened species), there is a need to develop a single platform from which these considerations can be assessed together. A search for a better understanding of the processes that underlie the observed changes and also the linkages between the various constituents of the food web is required. The construction of an ecosystem model provides such a framework where interactions between components of the ecosystem can be identified. The ecosystem state, structure and function in both past and present can be assessed and used to develop a better understanding of the ecosystem as a whole. Before one can explore the temporal and spatial dynamics in a system, it is necessary to describe a static snapshot of the ecosystem in terms of its constituents. Quantifying the system in terms of its biomass and trophic flows forms the foundation on which further exploration can be carried out using temporal and spatial drivers and assessing the potential ecosystem effects of such scenarios.

The wealth of scientific research that has been conducted at the PEIs provides a unique data set from which to build an ecosystem model. This work describes the first comprehensive ecosystem model of the marine component of the PEIs for three separate decades (1960s, 1980s and 2000s) as static mass-balanced entities. Such a model is necessary before exploring ecosystem dynamics, the ecosystem effects of fishing and conservation. Through the construction of this model, a dataset has been compiled, providing a useful summary of existing data for the system as well as highlighting data gaps. This, combined with an assessment of data quality and model sensitivity provides a decision support platform for assessing where scientific research efforts should be focussed in future to improve the model parameters and thereby the quality and usefulness of the model. Finally, an assessment of the ecosystem in terms of its trophic structure, biomasses, flows through the food web and relevant ecosystem indicators is presented.

2. Methods

2.1. Study area

For the purposes of the creation of the model, the study area has been set to be the exclusive economic zone (EEZ) of the Prince Edward Islands (Fig. 1). This area is demarcated with a circle, with a radius of 200 nm centered between the two islands (46°46′S, 37°51′E). The total area is equal to 431,014 km^2.

2.2. Modelling approach

The approach used for this study is the mass balanced network model, known as Ecopath (Christensen et al., 2008). The original 'Ecopath', first proposed by Polovina and Ow and developed by Polovina (Polovina, 1984, 1986; Polovina and Ow, 1985) combines a system of simultaneous linear biomass budget equations which balances biomass production and loss. Since its original formulation (Christensen and Pauly, 1992, 1993) the model has been developed so that it no longer relies on a steady state, and it incorporates a network analysis component from theoretical ecology for detailed assessment of the trophic flows (Christensen et al., 2004; Ulanowicz, 1986). These developments allow comparisons between ecosystems. Ongoing developments to the software have meant that this model is the fore-runner in its field. It has the capacity to represent all trophic levels. It is the most widely used and is appropriate for addressing broad ecological questions (Plaganyi, 2007).

In Ecopath, species can be considered individually, or pooled together into functionally related groups. Each group is represented by their biomass and the groups are linked through their trophic interactions. The basic Ecopath model is a closed system mass balanced formulation of the functional groups in an ecosystem and the full methodology can be found in the user's guide (Christensen et al., 2008).

There are two principal equations in the Ecopath model, the first, Equation (1), describes the production term within a group (i), and includes consumption, respiration and unassimilated mass metrics. The second, Equation (2), describes the production term of the group (i) within the system, taking into consideration all forms of mortality (separated into predation, fishing and other).

This results in a series of n simultaneous equations created (equivalent to the number of groups in the system), and solutions for the equations are calculated based on the assumption of mass balance within the system using a generalised method for matrix inversion (see Christensen et al., 2008). The routine solves for one of four parameters for each group: biomass, production/biomass ratio (P/B), consumption/biomass ratio (Q/B) or ecotrophic efficiency (EE). Three of the four parameters must be entered to calculate the one unknown. This means that the basic model parameters required include biomass estimates, diet compositions, assimilation efficiencies, catch rates (where applicable) and three rate measurements (consumption, production and mortality). If all of these data are available, the EE of each group can be calculated by the model.

For the model as a whole, the energy input and output of all living groups must be balanced (Christensen et al., 2008). In Equation (2), only the production term of a group is included. To ensure balance within each group, Equation (1) is used. In Equation (1), respiration is the one term conventionally not measured and so it is left to the model to estimate (though if desired, this can be entered using an alternative input structure in Ecopath). The two master equations of Ecopath can be considered filters for mutually incompatible estimates of flow with the result providing a possible picture of the energetic flows, the biomasses and their utilization (Christensen et al., 2008).

2.3. Data

Three models have been compiled for the PEIs to represent the ecosystem in three different decades, the 1960s, the 1980s, and the 2000s. Model parameter estimates were made to represent the