Ecological Modelling 255 (2013) 38–57

Contents lists available at SciVerse ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Trophodynamics of the eastern Great Australian Bight ecosystem: Ecological change associated with the growth of Australia's largest fishery

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ARTICLE INFO

Article history:
Received 17 May 2012
Received in revised form 21 January 2013
Accepted 23 January 2013
Available online 1 March 2013

Keywords:
Eastern Great Australian Bight
Food web model
Ecopath with Ecosim
Sardine
Sardinops sagax
Fishing impacts

ABSTRACT

We used the *Ecopath* with *Ecosim* software to develop a trophic mass-balance model of the eastern Great Australian Bight ecosystem, off southern Australia. Results provide an ecosystem perspective of Australia's largest fishery, the South Australian sardine fishery, by placing its establishment and growth in the context of other dynamic changes in the ecosystem, including: the development of other fisheries; changing abundances of apex predator populations and oceanographic change. We investigated the potential impacts of the sardine fishery on high tropic level predators, particularly land-breeding seals and seabirds which may be suitable ecological performance indicators of ecosystem health. Results indicate that despite the rapid growth of the sardine fishery since 1991, there has likely been a negligible fishery impact on other modelled groups, suggesting that current levels of fishing effort are not impacting negatively on the broader ecosystem structure and function in the eastern Great Australian Bight. Results highlight the importance of small pelagic fish to higher trophic levels, the trophic changes that have resulted from loss and recovery of apex predator populations, and the potential pivotal role of cephalopod biomass in regulating 'bottom-up' trophic processes. The ability to resolve and attribute potential impacts from multiple fisheries, other human impacts and ecological change in this poorly understood region is highlighted by the study, and will be critical to ensure future ecologically sustainable development within the region.

1. Introduction

There is growing concern about the global impacts of increased fishing effort on ecosystem structure and function. Much of this concern stems from the growth of fisheries that target low trophic level species (planktivorous small pelagic fish), which currently account for ~30% of global landings (Ainley and Blight, 2009; Branch et al., 2010). This growth has been largely driven by increased demand for fish meal production, feed or fertiliser for the aquaculture and agriculture industries and only a small portion is processed for human consumption (Alder et al., 2008; Merino et al., 2010; Naylor et al., 2009). Small pelagic fishes are recognised as important in marine ecosystems in the transfer of production from plankton to higher trophic level species (marine mammals, seabirds and large predatory fish), and concerns about the potential impacts on high trophic level species from localised depletion by fisheries has been identified by many studies (Cury et al., 2000, 2011; Jennings et al., 2012; Smith et al., 2011). Although some studies have successfully demonstrated the relationships between overfishing of low trophic level species and the impacts on higher trophic levels, especially seabirds (Cury et al., 2011; Frederiksen et al., 2005; Jahncke et al., 2004; Myers et al., 2007), the numerical and trophodynamic relationships between predators and prey are poorly understood, even in regions where there are commercially valuable fisheries (Abrams and Ginzburg, 2000; Cury et al., 2011). As such, numerical modelling of ecosystem dynamics is increasingly being utilised to resolve these complex relationships (see review by Fulton, 2010) and to achieve ecosystem based fishery management

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http://dx.doi.org/10.1016/j.ecolmodel.2013.01.006

(EBFM) objectives (Pikitch et al., 2004). The latter is dependent on the development of reliable indicators of ecosystem status and health (Cury et al., 2011; Lozano-Montes et al., 2011; Pikitch et al., 2004; Samhouri et al., 2009). The objectives underpin ecologically sustainable development (ESD) frameworks that form the basis for modern management of Australian fisheries; however, there are few examples where they are achieved or put into practice. They include: (i) avoid degradation of ecosystems, (ii) minimise risk of irreversible change to assemblages of species and ecosystem processes, (iii) obtain and maintain long-term socioeconomic benefits without compromising the ecosystem, and (iv) generate knowledge of ecosystem processes sufficient to understand the consequence of human actions (Pikitch et al., 2004).

The South Australian sardine (*Sardinops sagax*) fishery (sardine fishery) is Australia's largest fishery by mass of catch. It was established in 1991 to provide feed for the southern bluefin tuna (SBT, *Thunnus maccoyii*) mariculture industry in Port Lincoln, South Australia (Fig. 1) (Ward et al., 2005). Operated as a purse seine fishery, sardine catch within this region is centred on southern Spencer Gulf, Investigator Strait and the western Eyre Peninsula in the eastern Great Australian Bight (EGAB) (Ward et al., 2005). Spawning biomass of sardine was estimated to be ~165,000 t in 1995 (Ward et al., 2009), but it declined by over 70% to ~37,000 t in 1996 following an unprecedented mass mortality event, recovered to ~146,000 t in 1998 and then declined by over 70% again to ~36,000 t in early 1999 following a second mass mortality event (Ward et al., 2001). Between 1994 and 2001, fishery catches ranged between 2500 and 6500 t each year, but the total allowable commercial catch (TACC) was expanded and the harvest increased markedly to 42,475 t in 2005, and then stabilising around 30,000 t from 2007.

The EGAB supports high densities of small pelagic fishes, the dominant species being sardine and anchovy (*Engraulis australis*) (Ward et al., 2006). Other important small pelagic fish species include blue mackerel (*Scomber australasicus*), jack mackerel (*Trachurus declivis*), yellowtail scad (*T. novaezelandiae*), redbait (*Emmelichthys nitidus*), maray (*Etrumeus teres*) and saury (*Scomberesox saurus*). Primary and secondary production in the EGAB appears to be underpinned by a unique northern boundary current system, the Flinders Current (Middleton and Bye, 2007; Middleton and Cirano, 2002; van Ruth et al., 2010a, 2010b; Ward et al., 2006), the dominant oceanographic feature of which is coastal upwelling that occurs between November to May, especially off the Bonney Coast, Kangaroo Island and southern and western Eyre Peninsula (McClatchie et al., 2006; Middleton and Bye, 2007; van Ruth et al., 2010a, 2010b; Ward et al., 2006) (Fig. 1). This coastal upwelling has oceanographic, biological and ecological similarities to the larger and more productive eastern boundary currents that underpin the Benguela, Humbolt, California and Canary Current upwelling systems (Mann and Lazier, 1996; Middleton and Platov, 2003; Ward et al., 2006), although the latter typically have an order of magnitude higher productivity and small pelagic fish biomass compared to the EGAB (Guénette et al., 2008).

The rich pelagic resources of the EGAB underpin arguably the greatest density and biomass of apex predators to be found in Australian coastal waters. These include marine mammals such as pygmy blue whales (*Balaenoptera musculus brevicauda*), and >80% of Australia's populations of New Zealand fur seals (*Arctocephalus forsteri*) and Australian sea lions (*Neophoca cinerea*) (Branch et al., 2007; Goldsworthy et al., 2003, 2009), and the Australian fur seal (*A. pusillus doriferus*) (Shaughnessy et al., 2010). All seal species were

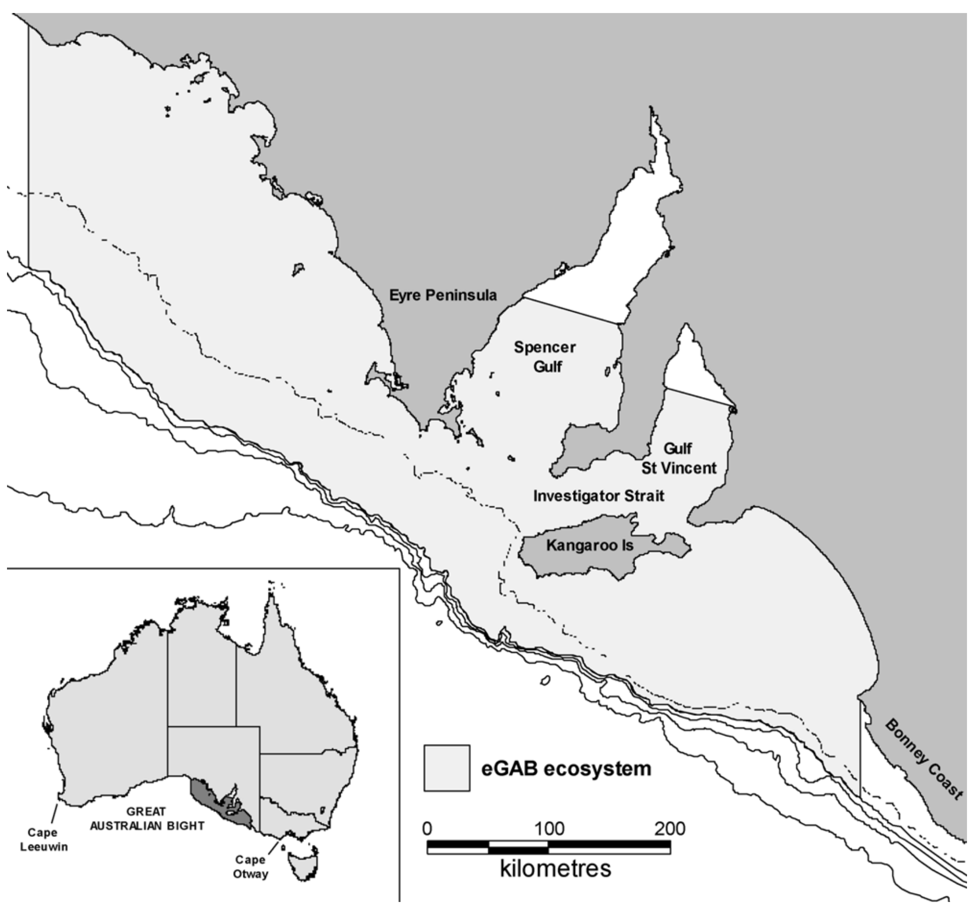

Fig. 1. Location of the eastern Great Australian Bight (EGAB) ecosystem included in the *Ecopath* with *Ecosim* model. The depth contours are 100, 200, 500, 1000 and 2000 m.