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Fish larval transport in a macro-tidal regime: Gulf of Kachchh, west coast of India

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ABSTRACT

This study combines observational data with a two-dimensional numerical model results to determine the fate of fish eggs released in the Gulf of Kachchh (GoK), a semi enclosed basin on the west coast of India. Fish eggs were treated as passive particles in the model, and were released from probable spawning sites identified from the field surveys. Areas with retention of larvae above 30% have been demarcated as nursery areas. Most of these nursery areas fall in ecologically significant sites which are rich in mangroves and reefs. We find that about 80% of the particles are retained in the basin for all the three prominent seasons prevailing in the GoK. Complete retention of particles in the southern Gulf region and small quantity of flushing out in the northern boundary of the Gulf could be a major reason for sustaining an abundance of larvae in the southern Gulf. Trawler catch data at various sampling points also suggest abundance of fish in the southern GoK region. Model simulation of fish larval transport in the GoK reiterates the fact that fish larval aggregation occurs in the southern GoK during active breeding phase with varying dispersal patterns from spawning sites. Marine protected areas in the Gulf demarcated based on the ecological significance of sites reasonably corroborate with the areas of likelihood of retention of fish larvae differentiated by the model.

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1. Introduction

Mangrove and coral reef ecosystems are the spawning and nursery grounds for a majority of fishes in the tropical coastal waters (Chittaro et al., 2004). The last two decades witnessed rampant destruction of coral reefs and mangrove ecosystem due to anthropogenic pressures and climate change (Chittaro et al., 2004; Mumby et al., 2004). Degradation of these ecosystems resulted in reduced recruitment of fish worldwide (Rogers and Beets, 2001) and it is not very different in the Gulf of Kachchh (henceforth will be termed as GoK in the text), a semi-enclosed basin along the west coast of India (Fig. 1). Establishment of industries very close to the coast resulted in destruction of flora and fauna, which is closely associated with the spawning and larval rearing cycle of fishes. GoK is famous for its fisheries potential (Vijayalakshmi et al., 1993). The collective contribution of fish production in the GoK during 2007–2008 was 18.8% to the total production of Gujarat State. During 2007–2008 total fish landing for Gujarat was 6.77×10^5 t, contributing about 22% to the total Indian production of 30.27×10^5 t. Fisheries management of the GoK is carried out on the archetype that local fishery is well mixed with the open waters, and closed areas are enforced as a protective measure for prospective nursery areas of fish (mangroves and coral reefs) (Singh, 2003). But, there is a possibility of self recruitment of fish taking place in the Gulf waters, which was not established in any of the earlier field studies. The irregular coastline of GoK along with shoals and reefs may trap water and inert particles. A semi-enclosed basin with sufficient retention time could retain fish larvae (Lobel and Robinson, 1986), zooplankton (Boicourt, 1982; Sammarco and Andrews, 1988; Murdoch, 1989; Thiebaut et al., 1994), phytoplankton (Roff et al., 1979) and other neutrally buoyant material (Wolanski and Hamner, 1988; Black et al., 1990).

The pelagic larval phase of fishes is responsible for their dispersion or retention (Cowen and Sponaugle, 2009), and during this phase fish larvae are considered as 'poor swimmers' (Leis et al., 2006) when the hydrodynamic forcing on the larvae exceeds its swimming ability, but there are proven cases where larval behaviour has influenced dispersal trajectories (Chia et al., 1984; James et al., 2002; Cowen et al., 2006; Aiken et al., 2007). The scale and predictability of measured fish larval dispersion or retention remain unknown largely due to the difficulty in measuring dispersion in open marine environments. Utilization of high-resolution biophysical model in estimating dispersal distance or retention time is advantageous as the models allow multiple releases of virtual fish eggs, thus making each individual simulation equivalent to numerous observations of dispersal event. These virtual observations provide information about expected variability in the hydrodynamics, and allow construction of a connectivity matrix with respect to larval dispersal (Cowen and Sponaugle, 2009). A

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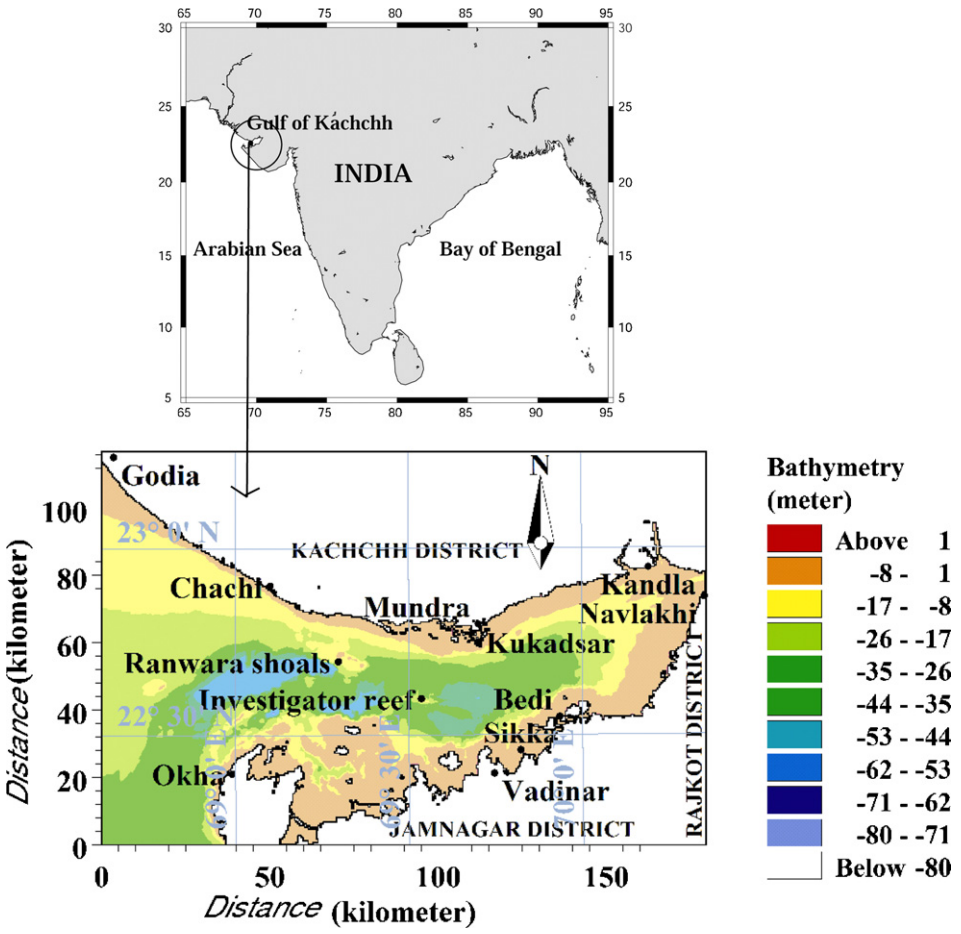

Fig. 1. Gulf of Kachchh and its topographic features.

common strategy employed in this kind of model is to predict the maximum likelihood of retention of investigated species based on habitat attributes (Guisan and Zimmermann, 2000; Moisen et al., 2006; Elith and Graham, 2009). Numerical modelling of fish eggs dispersion at the Patos Lagoon estuary in Brazil was carried out by Martins et al. (2007) using similar methodology.

No study has been carried out so far in the Indian coastal waters to determine the influence of physical forcing on fish larvae under which they are widely dispersed or locally retained. We want to assess whether the abundant fish population in the GoK is a manifestation of self recruitment by fishes trapped due to hydrodynamic or geographical barrier. We have released fish eggs as inert conservative particles from their representative spawning sites under a range of hydrodynamic conditions and associated dispersion processes unique to the GoK to simulate the spreading of eggs and transport of larvae. We have quantified percentage likelihood of retention/dispersal of fish larvae from spawning sites with the aim of identifying potential nursery habitats for fish in the Gulf.

2. Materials and methods

2.1. Study location and ecology

The GoK is located on the northwest coast of India, between 22°15′–23°00′N and 69°00′–70°15′E (Fig. 1), and is approximately 170 km long and 75 km wide at the mouth. Tidal range varies from 3 m at the mouth to 7 m upstream and tidal currents reach up to 2 m/s. The northern Gulf, which is predominantly sandy or muddy and confronted by shoals and creeks, also has large stretches of mangroves. The southern Gulf has numerous islands and inlets that has vast areas of mangroves and reefs with living corals. The southern GoK is a productive spawning ground for fishes with mangroves, coral reefs, seagrass beds and seaweeds. In order to protect the rich biodiversity of GoK, several long stretches of intertidal mudflats and coral reefs along its southern Gulf are declared as Marine National Park and Marine Sanctuary (Fig. 2). A variety of exposed and sheltered sites are present in the GoK and previous studies show the existence of three distinct eddies with diameter varying between 10 and 20 km in the western half of the GoK (Desa et al., 2002; Vethamony et al., 2004; Babu et al., 2005; Kankara

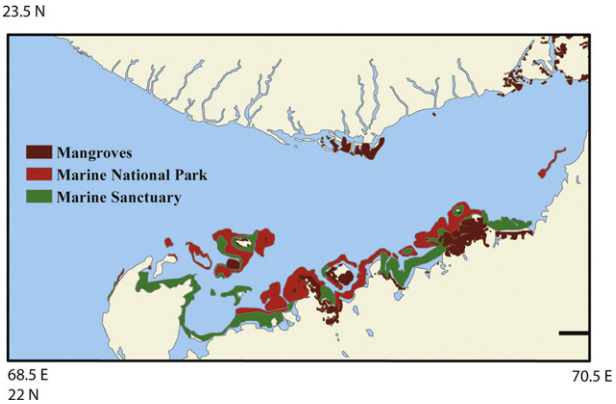

Fig. 2. Distribution of ecologically sensitive areas along the GoK (based on Desa et al., 2002).

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