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Recruitment and connectivity influence the role of seagrass as a penaeid nursery habitat in a wave dominated estuary

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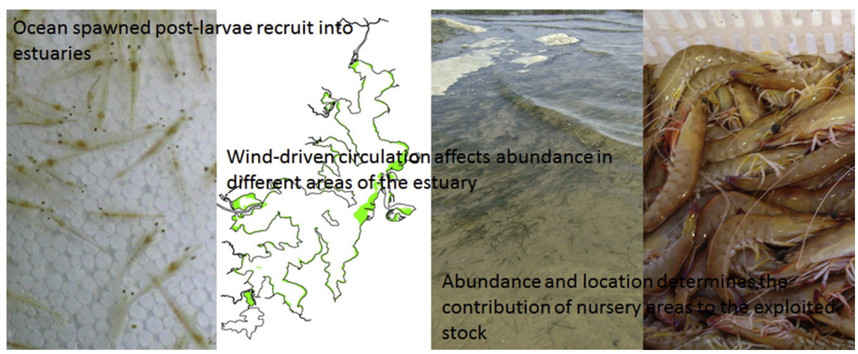
HIGHLIGHTS

- Abundance of prawns was affected by distance to the mouth, seagrass percent cover and temperature.
- Abundance depended on wind-driven currents during the recruitment season.
- Abiotic processes driving abundance ultimately determined the nursery role of habitat.

GRAPHICAL ABSTRACT



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ABSTRACT

Estuaries provide a diverse mosaic of habitats which support both juveniles and adults of exploited species. In particular, estuaries play an important role in the early life history of many penaeid prawn species. This study used a combination of stable isotope ecology and quantitative sampling to examine recruitment and the nursery function of seagrass habitats for Eastern King Prawn (*Penaeus* [*Melicertus*] *plebejus*), and the processes that contributed to this nursery role. Stable isotopes were used to assign prawns joining the adult stock to putative nursery habitat areas within the estuary. Emigrating prawns originated from only 11 of the 20 sites surveyed. Of these, 8 sites were designated as Effective Juvenile Habitat (EJH), and 5 sites designated as Nursery Habitat (NH). The contribution of individuals from different nursery areas to the adult stock was related to both the abundance of prawns within an area and the distance to the mouth of the estuary, and with the exception of 1 site all EJH and NH were located in the northern section of the estuary. Quantitative sampling in this area indicated that prawns were present at an average density of 165 ± 11 per 100 m^2, and density formed non-linear relationships with the distance to the mouth of the estuary, seagrass cover and temperature. Prawn size also formed non-linear relationships with prawn density and seagrass cover. Spatial patterns in abundance were consistent with wind-driven recruitment patterns, which in turn affected the nursery role of particular areas within the system. These findings have implications for targeted fishery restoration efforts for both Eastern King Prawn and other ocean spawned species in wave dominated estuaries where circulation is primarily wind-driven.

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1. Introduction

Successful recruitment depends on an adequate supply of eggs and larvae, availability of important habitats that maximise growth and minimise mortality, and connectivity between important habitats used across an organism's life history. Identifying important juvenile habitats is a key element of describing the recruitment cycle and has been the subject of a concerted research effort over previous decades. Estuaries are important nursery grounds and in more recent years research has sought to classify estuarine habitat as *nursery habitat* (habitat that makes a greater than average contribution-per-unit-area to the adult population, Beck et al., 2001), and *effective juvenile habitat* (habitat that makes a greater than average contribution to the adult population, Dahlgren et al., 2006). Consequently, determining whether a particular estuarine habitat functions as a nursery or effective juvenile habitat for a particular species involves quantifying this contribution. This can be achieved for fish by assigning adults to putative juvenile habitats on the basis of otolith elemental composition (Gillanders and Kingsford, 2000). Recently, progress has also been made using the stable isotope composition of muscle tissue to allow assignment of migratory species which lack permanent hard parts (e.g. crustaceans) to putative nursery habitats (Taylor et al., 2016b). Such research should ultimately improve how we manage habitats for exploited crustacean species, and the fisheries that depend on them.

Estuaries offer a variety of productive habitats to support juveniles of both estuary and ocean-spawned species. Ford et al. (2010) recently introduced the concept of settlement 'hotspots' in estuaries, and the impact that a greater supply of recruits can have in shaping which habitats are of high nursery value. This is particularly important for coastally spawned species, which often rely on favourable hydrographic conditions for advection to an appropriate settlement site (Forward et al., 2004; Hannan and Williams, 1998). Consequently, connectivity and supply-side ecology (Lewin, 1986) are fundamentally important in the role and function of estuarine habitats as nurseries (this is further reviewed in Sheaves et al., 2015).

There has been a substantial loss of estuarine fish habitats, including many potential fish nursery habitats in the last two centuries. Barbier et al. (2011) report a worldwide reduction in seagrass, saltmarsh and mangrove of 29%, 50% and 35% respectively. In Australia this may be as much as 45,000 ha of seagrass (Walker and McComb, 1992), and in New South Wales ~72% of the 'prime fish habitat' (62,000 ha, including saltmarsh and mangrove) that was present prior to European settlement has been lost (Rogers et al., 2015). Recent work in Australia and elsewhere has identified habitat restoration and rehabilitation as one of the few avenues of management whereby large gains in fisheries productivity can still be made (Sheaves et al., 2014). With such significant areas of habitat which can potentially be restored, prioritisation on the basis of fisheries outcomes is one approach to targeting restoration. In Australia, case studies indicate that restoration efforts targeted at enhancing valuable penaeid prawn species are likely to yield substantial economic benefits (Creighton et al., 2015). Effective targeting, however, relies on a comprehensive understanding of how aquatic organisms use estuaries, which habitats serve an effective nursery function, and where such habitats are located.

Penaeid species are valued for aquaculture and wild harvest across the world (Turner, 1977), usually representing high-value product. These species display a range of life-history strategies, but many commercially important species have Type-I or Type-II life cycles which include an estuarine nursery phase (Dall et al., 1990). Eastern King Prawn (*Penaeus* [*Melicertus*] *plebejus*) is one of the most valuable prawn species exploited off eastern Australia, harvested primarily from offshore trawl fisheries operating in northern New South Wales and southern Queensland. The species also spawns in this region (Montgomery et al., 2007), the larvae are subsequently transported south in the East Australian Current, and postlarvae are transported into estuaries (Rothlisberg et al., 1995). The species appears to be highly reliant on shallow littoral habitats in estuaries as nurseries (Halliday, 1995; Young, 1978), especially over summer, and can use different estuarine habitats to varying degrees (Ochwada et al., 2009). Following the nursery phase, prawns undergo a predictable emigration from the estuary during the last quarter of the lunar cycle (Racek, 1959), followed by a northward migration back to the spawning grounds (Braccini et al., 2012).

While the estuarine nursery phase of Eastern King Prawn is well described in its northern distribution, little is known about recruitment and the nursery function of different habitats in the southern estuaries which supply a large portion of the exploited stock (Montgomery, 1990). Using the largest coastal lake on the eastern Australian coast as a study system, we aimed to quantify the nursery role of different areas within the estuary by:

1. Conducting an estuary-wide survey of putative nursery habitat areas using a stable isotope-based assignment approach, and using this information to identify key nursery and effective juvenile habitats;
2. Comparing the nursery value with juvenile density and connectivity attributes of those areas;
3. Using targeted quantitative surveys to further resolve patterns of distribution observed in the broad-scale analysis, and factors driving this distribution.

2. Materials and methods

2.1. Study area

This study was conducted in Lake Macquarie, New South Wales (−33.09°, 151.66°), a large, immature, wave dominated barrier estuary (Roy et al., 2001), with a waterway area of 114 km^2. There are extensive seagrass beds, dominated by *Zostera capricorni* and *Posidonia australis*, but minimal intertidal and submerged rocky reef area. The estuary catchment is moderately developed and two power stations draw lake water for their condenser cooling systems, discharging warm water back in the southern half of the lake. The lake has a fairly stable salinity regime; however the power stations can exert a considerable influence water temperature (see Taylor et al., 2016a), which varies seasonally. The large lake exits to the sea through the Swansea Channel, a narrow channel of about 5 km in length, which is only 140 m wide at its narrowest point. Consequently, large volumes of water pass through this constriction on each tidal cycle, and emigrating Eastern King Prawn are intensively fished by recreational anglers in this channel over the summer using dip nets from boats (the most intensive fishing occurs during the months of January–March).

2.2. Sampling design and collection

Sampling was done from January 2014 to March 2015. The study design had two components: an estuary-wide survey (corresponding with Objectives 1 and 2), which was followed by a targeted quantitative survey, informed by the results of the estuary-wide survey (corresponding with Objective 3).

2.3. Estuary-wide survey of putative nursery habitats

The first component occurred during the first season of project (January–March 2014) and primarily focussed on using stable isotope composition to identify the source of adults emigrating from the estuary. Twenty putative nursery habitat areas were sampled around the lake system for juvenile Eastern King Prawn (EKP, Fig. 1). At each area, during the last quarter of the January and March lunar months, four ~100 m tows were done with a 26B-6C sled net (0.75 × 0.45 m mouth, 4 m length, 26 mm diamond mesh body and 6 mm octagonal mesh codend). A GPS waypoint was marked at the start and finish of each tow (to calculate tow-length), and water quality (temperature, salinity, dissolved oxygen and turbidity) was recorded at each site. Sled samples were immediately placed on ice and frozen for laboratory processing