# IDENTIFYING AND UNDERSTANDING NURSERY HABITATS FOR EXPLOITED PENAEID SHRIMP IN NSW ESTUARIES

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## The need for estuarine habitat rehabilitation

The vast majority of Australia's population lives on the coastal fringes (Birch, 2000). Given the geographic isolation of Australia, access to ocean waters from sheltered ports for trade has been a key factor in the location and development of larger communities. This, coupled with the aesthetic benefits and desirability of living close to the sea, has meant that most of our major cities, and many of our major regional centres, are concentrated around estuaries.

Rapid development of communities, industry and agriculture around estuaries in the early 20th century showed little regard for the importance of estuarine habitats to species exploited for food or the health of ecosystems as a whole. Reclamation through infilling has seen the demise of extensive coastal wetland and mangrove habitats (e.g. Evans and Williams, 2010), and the installation of flood gates has seen the widespread loss of connectivity between coastal wetlands and estuarine waters. This has contributed to a reduction of some 72% of prime fish habitat available to support estuarine fish species (Rogers et al., 2015). In the estuarine waters themselves, various anthropogenic pressures have seen the degradation and loss of about 45,000 hectares of seagrass (Walker and McComb, 1992).

Recently, the case for extensive estuarine habitat rehabilitation in Australia has been developing. A recent business case suggested that relatively simple remediation activities can lead to substantial economic benefits (Creighton, 2013) through enhancement of the various ecosystem services derived from estuaries, especially fishery productivity. On this basis of this assessment, investment of the AUD350 million (Australia-wide) needed to undertake the necessary repair is expected to be recouped through these enhancements within 5 years (Creighton et al., 2015). To encourage investment in habitat repair, there is a need to prioritise and plan works to maximise benefits, and also to employ reliable analyses to place a financial value on these benefits.

Given the large volume of harvest, high value of product, and general reliance on estuaries during their life history, it has been suggested that habitat rehabilitation should focus on areas of potential benefit to penaeid prawn species (Creighton et al., 2015). This manuscript summarises some very recent data collected for penaeid prawns in NSW, and uses these patterns to show how the nursery concept can support the prioritisation, planning, design and assessment of estuarine habitat rehabilitation projects in New South Wales.

**Establishing nursery value and use in the planning habitat rehabilitation**

The estuarine nursery concept is a long-standing paradigm in marine ecology (Boesch and Turner, 1984), and suggests that the structural complexity and productivity of estuaries plays a significant role in the growth and survival of early stages of marine organisms. This in turn affects the abundance at later stages when these organisms reproduce, and can be exploited for human consumption. A large proportion of exploited species in south-eastern Australian estuaries utilise estuaries for some component of their lives, with levels of usage ranging from a few short months during an organisms early life history (i.e. the nursery stage) to the entire life cycle of an organism.

Penaeid prawns are among the most heavily exploited benthic crustaceans in the world. Many penaeid species display a Type-II life cycle, whereby spawning occurs in oceanic areas, young prawns recruit into estuaries for their juvenile stage, and migrate back to the ocean as they mature (Dall et al., 1990). During this period, young prawns are thought to be reliant on both the overall productivity for food, and the various habitats available in estuarine systems for shelter, but this varies between species. The overall dependence of these taxa on estuaries is however highlighted by Turner (1977), whose meta-analysis shows a strong positive correlation between estuarine habitats (intertidal vegetation) and landings of penaeid prawns, which transcends species and geographic areas.

Along the length of the NSW coast, the two major species of penaeid prawns that use estuaries are Eastern King Prawn (*Penaeus plebejus*) and School Prawn (*Metapenaeus macleayi*). Both species display a penaeid Type-II life-cycle, but display different levels of estuarine usage. Eastern King Prawn spawn off northern NSW and southern Queensland, and their larvae develop as they drift south in the Eastern Australian Current (Everett et al., in review). As they reach their postlaval stage, they emigrate inshore and into estuaries, where they settle out across a range of different habitats. They remain in the estuary for 2-3 months, before emigrating to inshore areas and commencing an extensive migration toward the spawning areas further north (Braccini et al., 2012). School Prawn spawn in inshore areas, usually adjacent to the mouth of an estuary, recruit into the estuary as postlarvae, and rely on estuarine habitats during their juvenile phase (Racek, 1959). Maturing prawns emigrate from the estuary usually within the months of December – March, and spawn around the mouth of the estuary from which they emigrated, or adjacent estuaries to the north (usually within about 70 km, Ruello, 1977). School Prawn are highly exploited in their estuarine and inshore phase (Glaister, 1978), whereas Eastern King Prawn are primarily exploited in their offshore migratory phase (Gordon et al., 1995).

While these species both use estuaries, they are not ubiquitous and are present in different numbers at different places, and in different habitats. If estuarine habitat rehabilitation is to be targeted at the enhancement of these valuable species, understanding the nursery *value* of different areas within the estuary, and the processes that might be driving these patterns, will allow managers to: 1) prioritise areas for rehabilitation that are likely to result in the greatest benefits for these species; 2) give regard to factors that may increase nursery value when engineering rehabilitation works; and 3) estimate the potential outcomes of different rehabilitation scenarios for different species.

## Nursery habitats for exploited penaeid shrimp in NSW estuaries

Defining nursery value is most commonly approached through the designation of different areas within the estuary as *nursery habitats*. The general definition of a nursery habitat is one that contributes a disproportionate number of recruits to the exploited or reproducing components of the population (Beck et al., 2001). This usually involves tracing individual animals captured in the exploited or adult components of the population, back through space and time, to the location where they grew up, and using the contribution of different putative areas or habitats to derive a standardised contribution (i.e. contribution-per-unit-area of habitat). Habitats or areas that have a greater than average contribution-per-unit-area, are generally designated as *nursery habitats*. The spatial extent of the habitat or area from which an animal originates, however, may not always be explicitly defined. In these cases, a simpler method is used to assess nursery value, which only considers total contribution of a habitat or area regardless of its spatial extent (Dahlgren et al., 2006), and defines areas that have a greater than average contribution as *effective juvenile habitat*. While these two approaches provide suitable methods for assessing nursery value, Sheaves et al. (2015) highlight that a broader suite of variables need to be considered, including the supply of natural recruits to a particular habitat, limitations imposed by an organisms physiology, requirements for refuge habitat, and connectivity between juvenile and adult habitats.

Considering the information above, tracing older animals back to their juvenile habitat is an important component of understanding nursery value. For fish, this is often achieved by using the concentrations of certain elements laid down in the fishes otolith (Elsdon and Gillanders, 2003), but this is most often used to classify individuals among different estuaries. Similar approaches have been trialled for crustaceans, but similarly only work at broader spatial scales (Courtney et al., 1994). Taylor et al. (2016) recently developed a method for assigning penaeid prawns to particular areas within an estuary, using the stable isotope signature of muscle tissue. This two part process involves firstly collecting animals from across the estuary (i.e. in putative nursery habitat areas) to develop a library to which animals of “unknown origin” can be assigned. The second part of the process involves collecting animals as they emigrate from the estuary to join the adult or exploited component of the population, and matching the muscle stable isotope signature from these individuals to putative nursery habitat areas to derive the most likely area from which they originated. This novel approach was used in conjunction with traditional trawl sampling to define nursery habitats and effective juvenile habitats for Eastern King Prawn and School Prawn across a number of estuaries in NSW, and quantify how completed rehabilitation projects were benefiting these species.

Lake Macquarie is a large, immature, wave dominated barrier estuary, and NSW’s largest coastal lake with a waterway area of 114 km$^2$. The lake has a small tidal range, a relatively stable salinity regime, and extensive seagrass beds dominated by *Zostera* and *Posidonia*. Using the approach described above, Taylor et al. (in review) assigned Eastern King Prawn that were emigrating from the estuary among 20 putative nursery habitat areas (School Prawn do not occur in the estuary in large numbers). Over 80% of the emigrating prawns could be assigned among these areas, although they were only assigned to 11 of the areas surveyed. The level of contribution from these areas was significantly related to both the abundance of prawns within an area and the distance of that area to the mouth of the estuary. Given the definitions outlined above, 8 areas were designated as effective juvenile habitat (EJH), and 5 areas were designated as nursery habitat (NH). All of the EJH and NH were located in the northern section of the estuary. The isotope sampling was followed up in the following year by quantitative sampling aimed at evaluating the absolute densities of prawns present in each area. These results supported the patterns observed from the isotope analysis conducted in the previous season. Prawn densities were significantly related to distance to sea, and densities were greatest at a distance of 6-9 km from the estuary mouth.

Examination of circulation and wind patterns led to the conclusion that tidal transport of incoming postlarvae could not explain the recruitment patterns. Rather, the spatial patterns in abundance were consistent with transport from the end of the lakes entrance channel being driven by predominantly southerly winds during the recruitment season. Ultimately, the supply of recruits through wind-driven transport, and the density of seagrass in a particular habitat, was most important in determining whether a habitat was a nursery habitat or effective juvenile habitat. Other ocean-spawned species also recruited at greatest densities to these areas (Hannan and Williams, 1998).

The second estuary examined was the Hunter River Taylor et al. (in preparation), a mature, wave-dominated barrier estuary located just to the north of Lake Macquarie. While the lower estuary is heavily urbanised, it has abundant mangrove and saltmarsh habitats, and includes 4 main features: 1) an expansive mangrove lined system of shallow embayment's (Fullerton Cove and Fern Bay); 2) Tomago wetland to the north; 3) Kooragang wetland, which is nested between the north and south arms of the lower estuary; and 4) Hexham wetland in the south. The historic installation of dykes and floodgates removed connectivity of three wetland systems and the main estuary, however several recent rehabilitation projects have reinstated this connectivity, initially to Kooragang wetland (Williams et al., 2000) followed by Tomago (Rayner and Glamore, 2010) and most recently the Hexham wetland was rehabilitated (Boys and Pease, 2016).

Using the approach employed by (Taylor et al., 2016), up to 93.5 % of prawns could be assigned to putative nursery habitat areas. Emigrating Eastern King Prawn were primarily assigned to the higher salinity areas of the lower estuary, with most originating from the shallow, unvegetated habitats of Fullerton Cove and Fern Bay, and sites in these are were all designated as effective juvenile habitat (designation of nursery habitat was performed with this data). The wetland systems mentioned above made only minor contributions to the emigrating component of the population. The relationship between distance to sea and abundance was not linear, however, and quantitative sampling revealed a distinctive peak in between 8 and 10 km from the estuary mouth, and also that prawns were more abundant in shallower water. This area corresponded with a salinity primarily in the range 26-32. The isosmotic salinity for juvenile EKP is 28 (Dall, 1981), and recent physiological experiments have shown that energetic efficiency is greatest at this salinity (Tyler et al., in review), allowing for optimal somatic growth. Bathymetry, salinity, and connectivity ultimately affected the nursery value of different areas for Eastern King Prawn in the Hunter River.

For School Prawn in the Hunter River, the contribution of different areas to emigrating prawns was spread much more evenly across the lower estuary, and the three main wetland areas described above were designated as effective juvenile habitat for this species. Abundance of School Prawn was also positively related with distance to the mouth of the estuary, and preliminary examination of the patterns indicated that fishing effort may affect the contribution of different areas to the emigrating component of the population.

## Applying knowledge of penaeid nursery value to habitat rehabilitation

The information above presents some clear patterns which highlight areas of particular nursery value in two contrasting estuaries, and the factors that influence this value. This information is extremely useful in evaluating existing habitat rehabilitation efforts, and informing future efforts.

The patterns resolved for Eastern King Prawn in Lake Macquarie have implications for targeted fishery restoration efforts, both for Eastern King Prawn as well as other ocean spawned species in wave dominated estuaries. It is clear that under natural recruitment conditions, those habitat rehabilitation strategies targeting seagrass (such as replacement of traditional moorings with seagrass friendly moorings) should have the greatest positive impact on this species when efforts are targeted toward locations where hydrographic patterns provide the greatest number of recruits, which in the case of Lake Macquarie is 6 – 9 km inside the estuary mouth.

In the Hunter River, the patterns presented indicate that a number of factors combine to determine the nursery value of different areas within an estuary. For Eastern King Prawn, these were bathymetry, connectivity and salinity. The importance of shallow estuarine areas in the lower estuary highlight the potential impact that extensive loss of high nursery value habitat through land reclamation throughout the lower Kooragang Island may have had on the species (Williams et al., 2000). It also shows that improving tidal connectivity from the south arm into the lower Kooragang wetland could lead to increased value of this habitat for Eastern King Prawn. Due to its small relative waterway area, the Hexham wetland was not designated as an effective juvenile habitat for Eastern King Prawn, however, the highest abundances encountered during the research were present in the subtidal channels of this recently rehabilitated wetland system. The Hexham wetland certainly appears to be of high nursery value for Eastern King Prawn as it receives good recruitment, suitable salinity and a shallow sub-tidal channel system. For School Prawn, all rehabilitated wetland systems were of high nursery value.

These points represent preliminary recommendations and conclusions as field research is being finalised and published. An important use of this data will be application of the abundance information through a fishery model to predict the economic benefits that may be derived from different habitat rehabilitation scenarios for these species. In recent years, examples of such modelling have emerged for Australia (e.g. Blandon and zu Ermgassen, 2014), although there has not yet been a dedicated study in NSW. Future work may also apply the approach described above to other valuable taxa, such as Mud Crab and Blue Swimmer Crab, to identify critical factors affecting nursery value and provide data to model the potential outcomes from habitat rehabilitation.

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