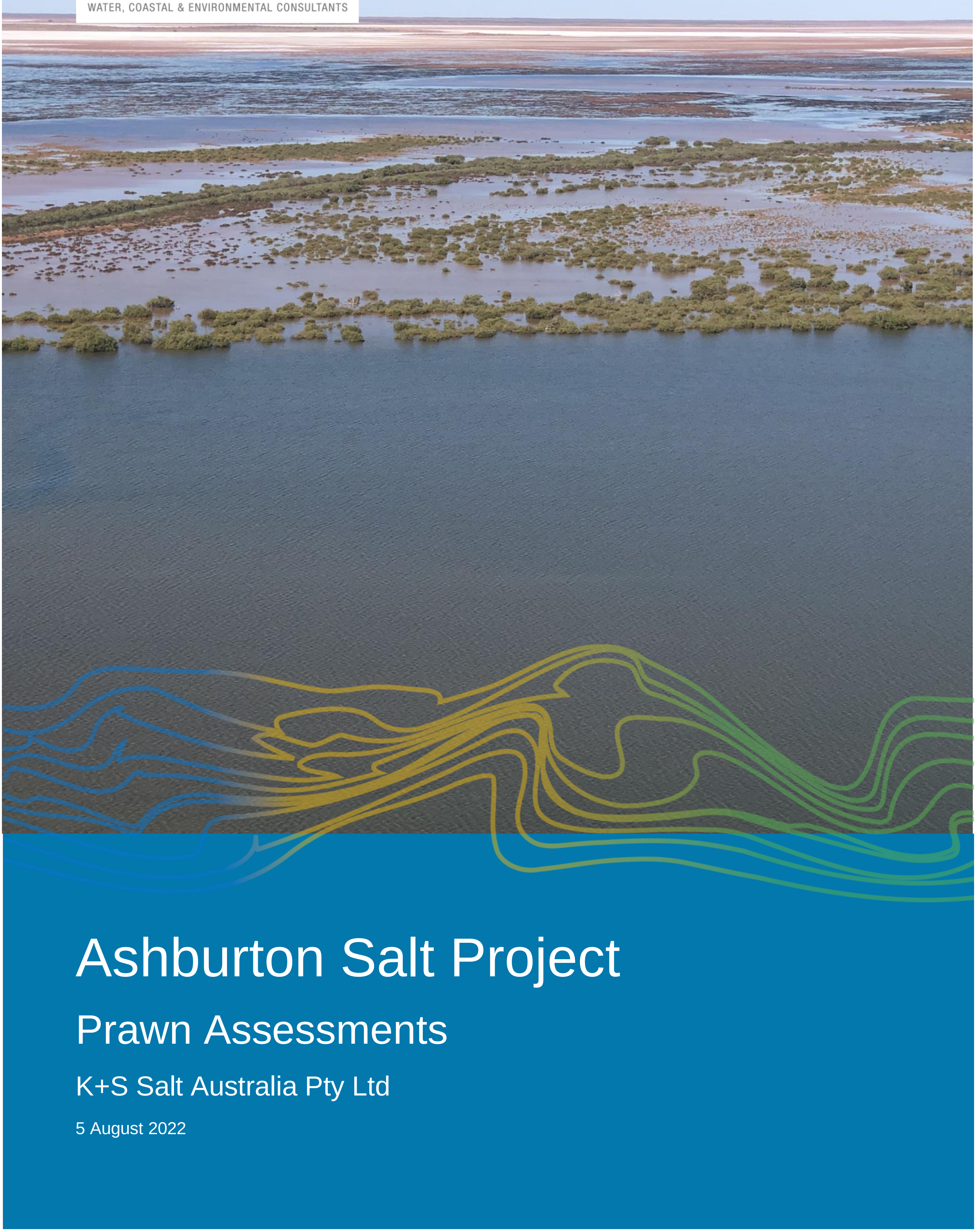

Ashburton Salt Project

Prawn Assessments

K+S Salt Australia Pty Ltd

5 August 2022

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1 INTRODUCTION

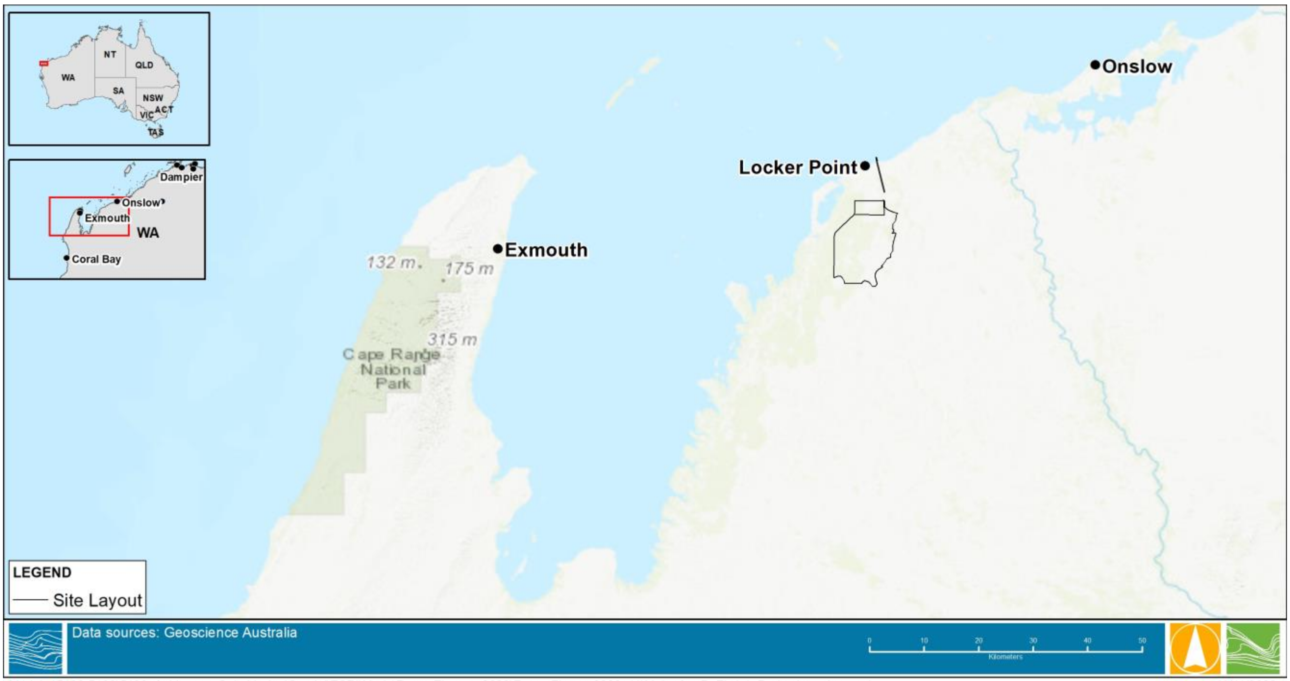
K+S Salt Australia (K+S) is proposing to construct a solar salt evaporation facility (the Ashburton Salt Project) approximately 40 km south west of Onslow. The location of the proposed Project is presented in Figure 1-1 and Figure 1-2.

The facility will require a range of infrastructure to be constructed, including a seawater intake and hypersaline wastewater (bitterns) outfall, as well as a jetty and berthing pocket to allow for export of the salt product. The operational layout will be constructed on existing salt flat areas that are located inshore from the coast.

K+S commissioned Water Technology to undertake an agent-based modelling (ABM) study to assess the potential impacts of the intake and outfall on prawn populations in Exmouth Gulf. This study has been a collaborative effort with extensive stakeholder engagement with participants from DPIRD, MG Kallis and Murdoch University.

This report focuses on the description of the agent-based model, specifically, it includes:

- Development of a calibrated hydrodynamic model across marine, nearshore and coastal areas;
- Development of an agent-based model that can simulate the life cycle of three different prawn species throughout Exmouth Gulf; and
- Quantification of the potential impact of the bitterns discharge and seawater intake on the three prawn species.



Data sources: Geoscience Australia

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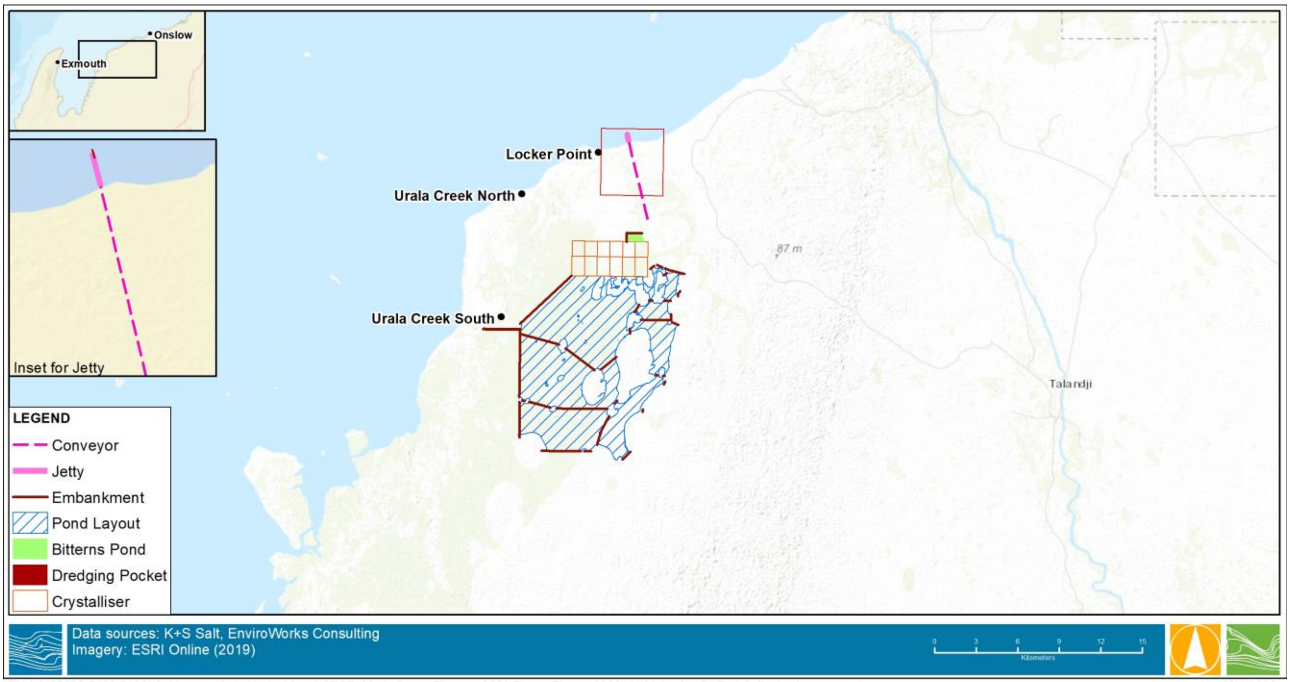
Figure 1-1 Project Location



Data sources: K+S Salt, EnviroWorks Consulting
Imagery: ESRI Online (2019)

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Figure 1-2 Proposed Project Layout

2 BACKGROUND

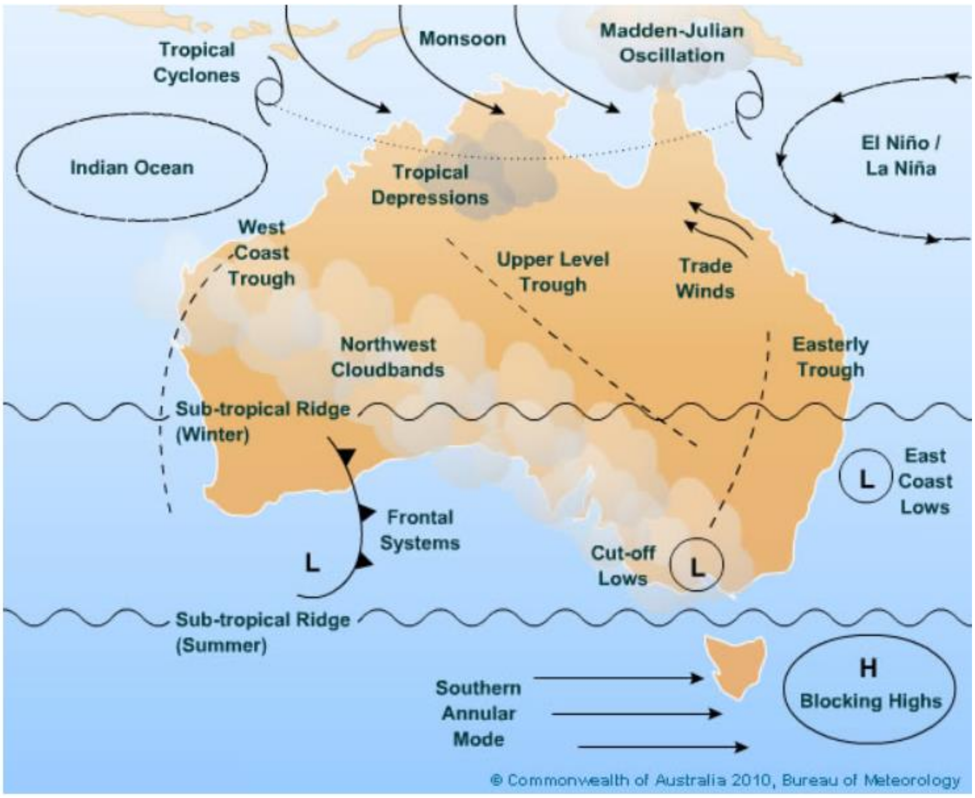
2.1 Exmouth Gulf

Exmouth Gulf is a large (~4000 km^2) and shallow (predominately < 20 m) tropical gulf located in a transition zone between the fully tropical waters of the northern coast of Western Australia and the more temperate waters of the southwest region (DPIRD, 2020). The Gulf is open to the north and enclosed by the Cape Range and large sand beaches to the west and a narrow band of mangroves bordering extensive salt flats which lead on to arid plains to the east and south. As shown in Figure 1-1, the Ashburton Salt Project is located in the northeast region of Exmouth Gulf.

The climate in the Gulf and at Ashburton is classified as hot and semi-arid, with rainfall occurring from January through to July. The dry season occurs from late August through to December. There is a tropical cyclone season that runs from the middle of December to April, with a peak occurring in the wet months of February and March.

Key climatic drivers are illustrated in Figure 2-1, presented by the Bureau of Meteorology (BOM, 2022). Along the Pilbara coast, the Indian Ocean Dipole, West Coast Troughs and Northwest Cloudbands dominate climatic conditions. In addition to this, the position of the subtropical ridge influences the seasonal change as the ridge shifts to the south in summer and to the north in winter, resulting in contrasting wet and dry seasons, respectively.

The existing environment at both a local and regional scale is described comprehensively in *Marine, Coastal and Surface Water Existing Environment* (Water Technology, 2021). A brief summary of components pertinent to the study is provided in subsequent sections of this report.



© Commonwealth of Australia 2010, Bureau of Meteorology

Figure 2-1 Australian Climate Drivers (BoM 2010)

2.1.1 Wind Conditions

Dominant weather conditions around Exmouth Gulf are governed by:

- A synoptic sub-tropical high-pressure belt to the south; and
- A trough of low pressure that typically extends over the inland Pilbara region during the summer months

These two processes contribute to a general south or south-westerly wind regime for the majority of the year, with more south-westerly winds common during the summer months.

On a daily scale, sea breezes are an important local-scale weather phenomenon. These breezes are generated by temperature differences between the land and the ocean and result in a strong contrast in wind conditions during the day. Generally, the daily variation in temperature of the land surface is greater than that of the ocean surface. Overnight, the land mass cools more than the ocean, resulting in lower air pressure over the ocean and a drawing of air towards the ocean from the continent. In the case of Ashburton, this is an easterly wind. Through the day, as the landmass heats more than the ocean, the air pressure rises over the ocean and air is drawn towards the coast, i.e. from the west or northwest.

Wind data recorded at Onslow Airport, Learmonth Airport and Barrow Island Airport has been reviewed. Wind roses showing wind direction and speed at Onslow Airport, Learmonth Airport and Barrow Island Airport stations for the period of record are presented in Figure 2-2. The three stations show varying wind conditions in line with their location on the coast and surrounding landforms.

Wind conditions at Learmonth Airport are dominated by south-westerly winds, with a strong southerly morning wind overshadowing lighter and more variable winds later in the day. Wind speeds are generally less than 7.5m/s, with stronger winds above 10m/s more common from the south-southwest, particularly during the summer months.

At Onslow, the wind climate is more variable and shows more westerly components compared to Learmonth, located on the western shore of Exmouth Gulf. The winds at Onslow are considered more typical of those likely to be experienced at Ashburton and as such the wind climate has been further analysed into winter (May through August), cyclone (mid-December through April) and dry (September to mid-December) season periods; noting as follows:

- Winter winds are largely northerly or southerly, with wind speeds less than 7.5m/s;
- During the cyclone season, winds continue to be dominated by westerly conditions, however some additional northerly component is present, increasing towards the end of the season in April. Outside of a cyclone passing, winds are generally less than 10m/s, although strong winds are observed from the west and west-northwest; and
- During the dry season, dominant winds are from the south through to west, with very little wind from the north through east to south. Wind speeds are stronger during this period, peaking through November when westerly breezes dominate. Winds can exceed 10m/s during this period from the west.

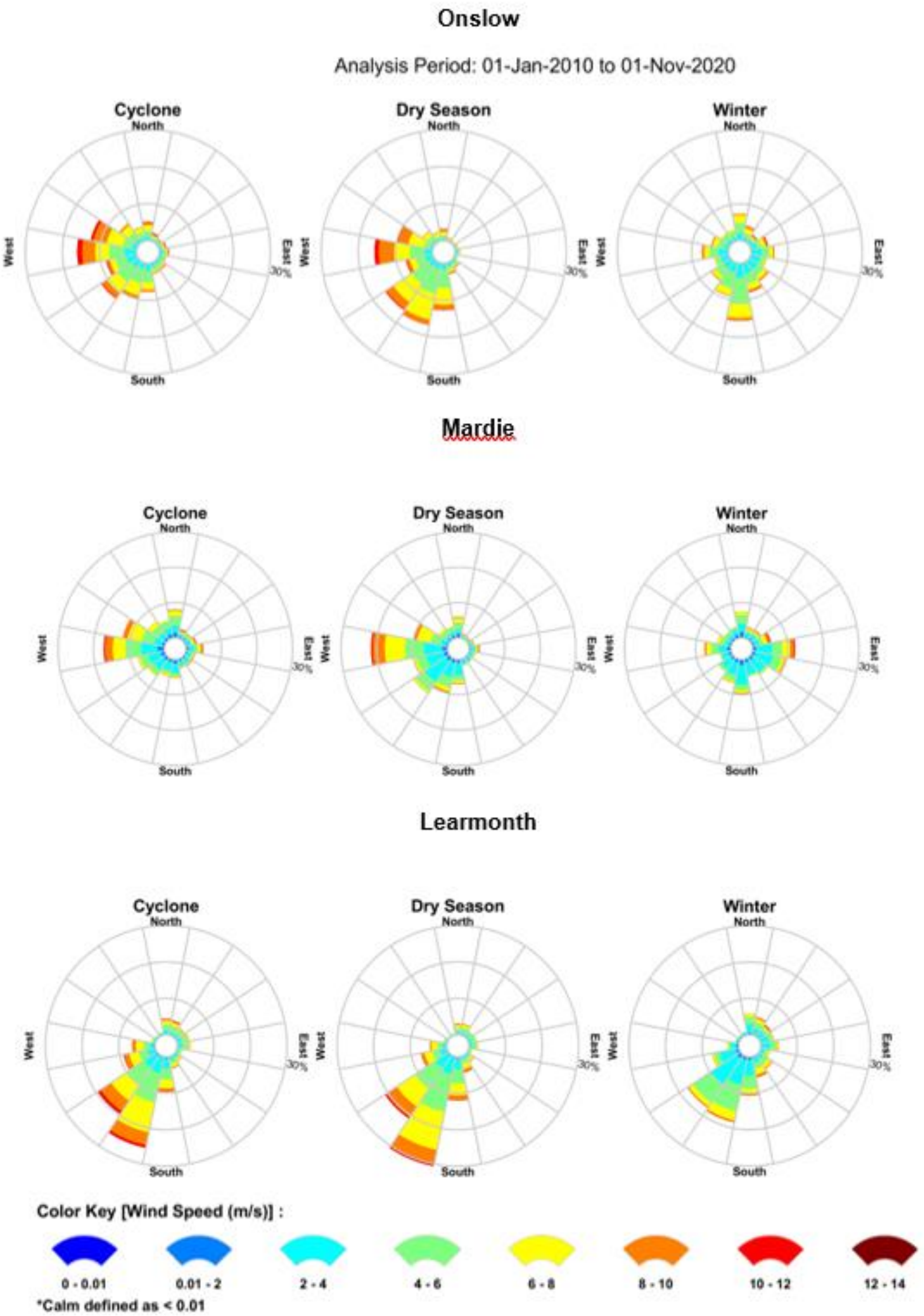


Figure 2-2 Exmouth Gulf Seasonal Wind climate

2.1.2 Oceanographic Conditions

Oceanographic conditions at the proposed facility and within Exmouth Gulf are driven by variations in climate described previously, astronomical tides and ocean currents such as the Leeuwin Current.

The site is located within the Indo-Australian Basin, the region of ocean between the northwest coast of Australia and the Indonesian islands of Java and Sumatra. Dominant currents relevant to the study site include the:

- South Equatorial Current;
- Indonesian Through-Flow (ITF);
- Eastern Gyral Current;
- Holloway Current; and
- Leeuwin Current.

Figure 2-3 illustrates the main surface currents of the region (DEWHA, 2007). All of these current systems experience strong seasonal to inter-annual variations, which indicate that they are likely to be influenced by climate change over the coming decades. Although there are strong seasonal trends, there are also periods when strong winds can cause intermittent reversals of these currents, with occasional weak upwellings of colder deep water. The Ningaloo Current is one such current which can strengthen in summer and cause upwelling on the shelf.

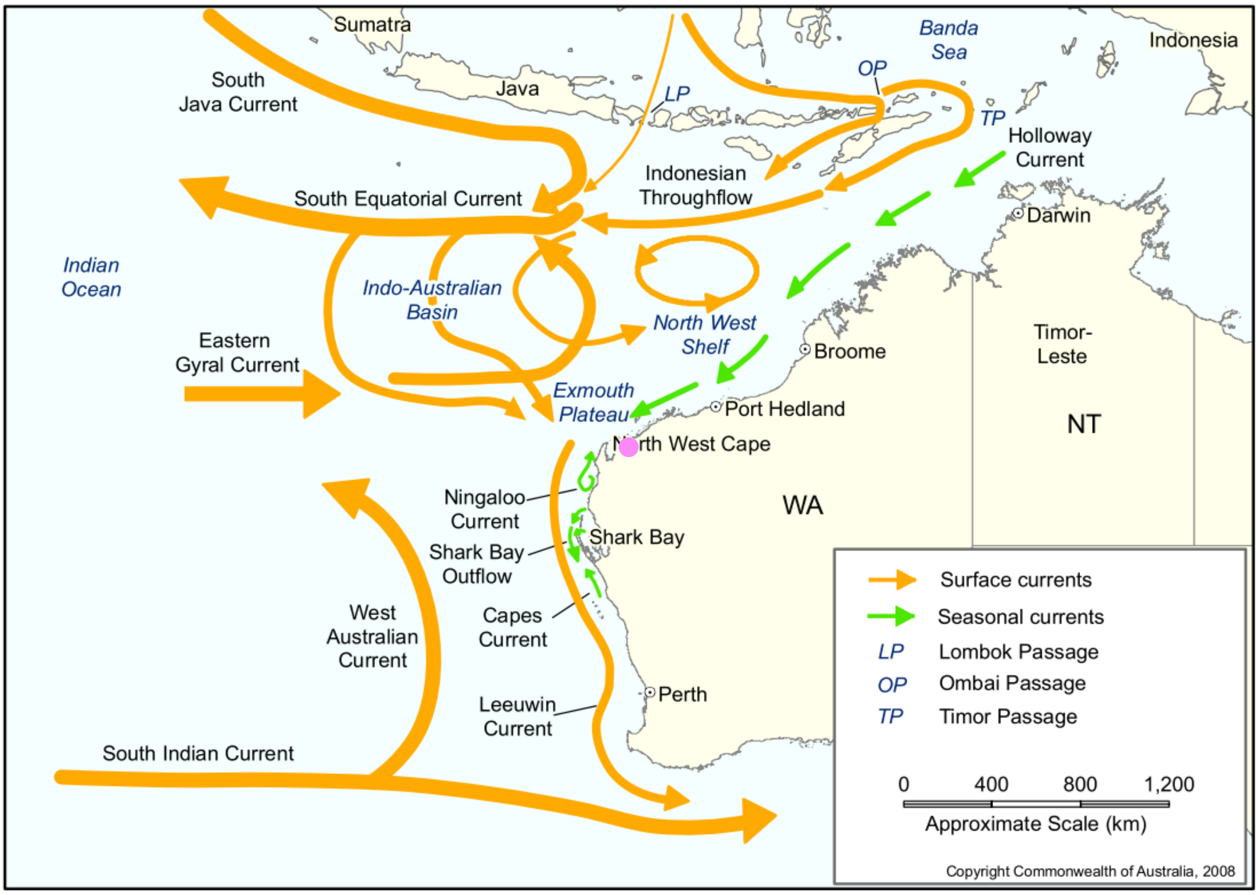


Figure 2-3 Regional oceanography and currents (DEWHA 2007). Approximate facility location indicated by the pink dot

2.1.3 Seagrass

Comprehensive benthic habitat information for Exmouth Gulf is limited and the majority of existing habitat data is focused on shallow inshore areas within the Exmouth Gulf Prawn Managed Fishery (EGPMF) nursery area. Mapping of seagrass in particular is integral to understanding prawn distributions throughout Exmouth Gulf as it is a key habitat for post-larvae and juvenile prawns. Seagrass is affected by light availability and therefore it can vary seasonally. Seasonal habitat mapping was created by DPIRD and provided for use in the ABM. Macroalgae mapping for the wet season, and dry season is shown in Figure 2-4.

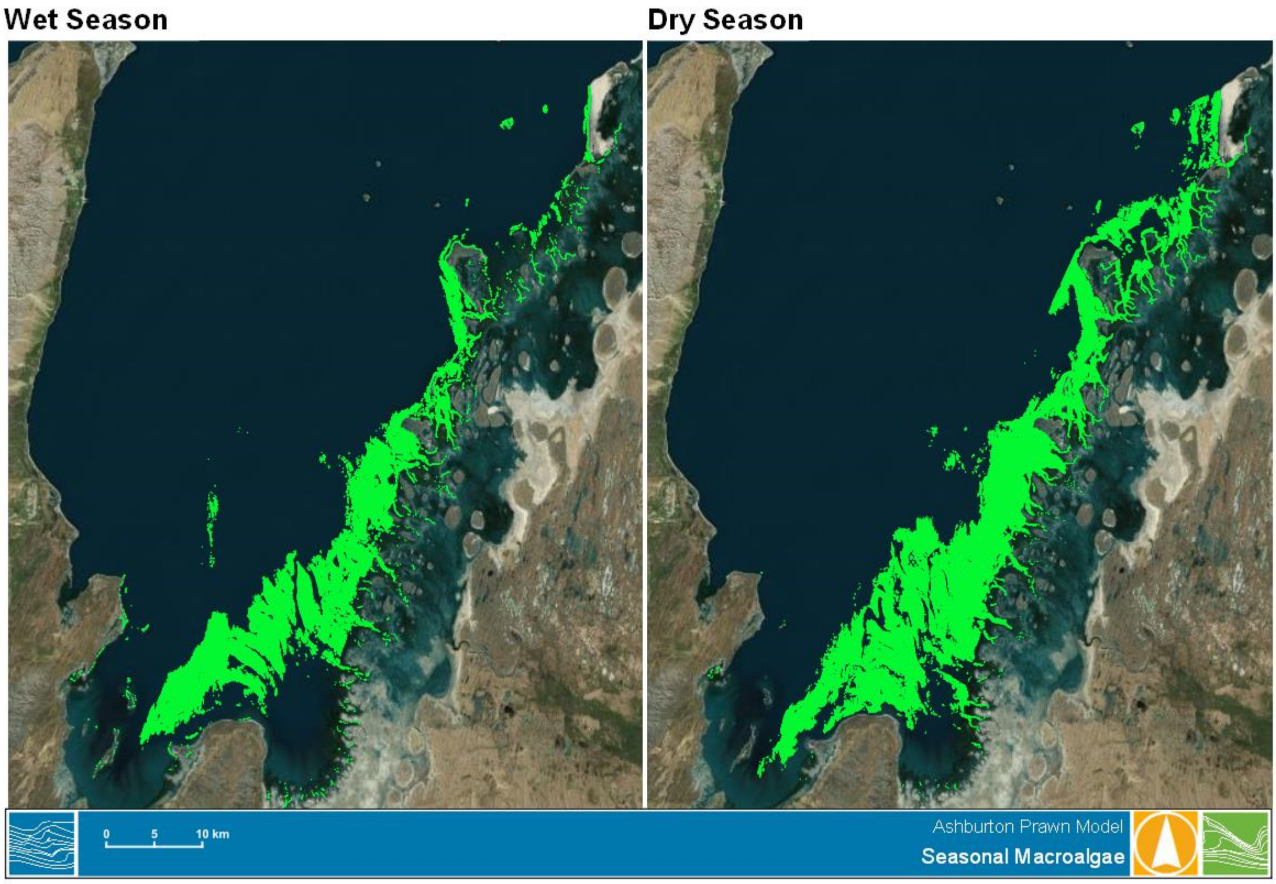


Figure 2-4 Seasonal seagrass mapping

2.1.4 Exmouth Gulf Prawn Managed Fishery

The EGPMF covers an area of ~2,790 km^2, or 70% of Exmouth Gulf, with the remaining 30% permanently closed to trawling (see Figure 2-5). The EGPMF targets prawns using low-opening demersal otter trawl nets. It has an estimated annual value of $10-20 million, landing around 500 to 1400 tonnes per annum. There are currently 15 managed fishery licences, all of which are held by a single licensee.

The three target species of the fishery are Blue endeavour prawns (*Metapenaeus endeavouri*); Western king prawns (*Penaeus (Melicertus) latisulcatus*); and Brown tiger prawns (*Penaeus esculentus*). The proposed development is located adjacent to the EGPMF. Urala Creek South, where the intake is located, is within the designated nursery area. Concerns were raised by the Fishery Licensee that the development could impact the prawn population as juveniles are drawn into the intake or interact with the bitterns discharge.

Extensive stakeholder engagement was undertaken during the prawn model development, so that DPIRD and the licensee would have confidence in the model development and eventual impact assessments.

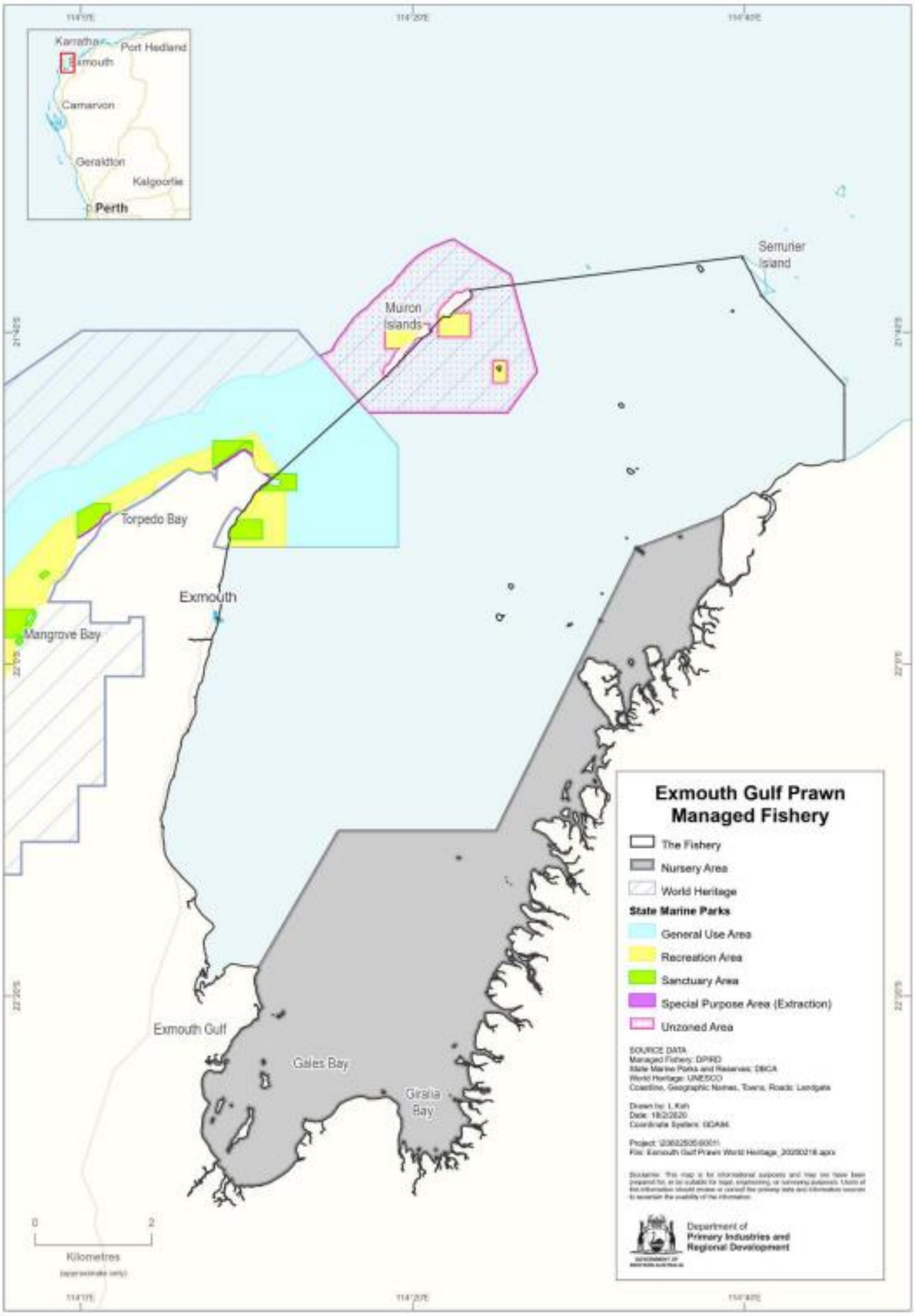


Figure 2-5 Exmouth Gulf Managed Prawn Fishery

2.2 Prawn Species

There are three key prawn species targeted by the EGPMF, and these were selected for modelling assessment. A fourth prawn species prevalent in the Gulf, Banana prawns (*Penaeus merguiensis*), was excluded from the assessment as they are only a minor species and there is also limited information on their spawning habits making their incorporation into the model challenging.

A summary of life cycle, important movements and key habitats for each species has been summarised from DPIRD (2015) and is detailed in the sections below. It is these important life cycle movements that will be incorporated into the ABM.

2.2.1 Brown Tiger Prawns

The brown tiger prawn (*Penaeus esculentus*) is a decapod crustacean of the family Penaeidae. The species is easily identified by its pattern of distinctive pale brown and darker bands as shown in Figure 2-6. Brown tiger prawns are generally regarded as endemic to Australia and are distributed around the northern coast, from central New South Wales in the east to Shark Bay in WA.

Figure 2-6 The brown tiger prawn. Illustration © R. Swainston (www.anima.net.au)

Penaeid prawns need to move between different habitats to complete their lifecycle, which is shown in Figure 2-7. Dall et al. (1990) describe these migrations as a larval and postlarval migration from the spawning ground to the nursery ground; a juvenile migration out of the nursery area; and an adult migration to deeper offshore water to spawn.

Although spawning female brown tiger prawns are found in WA between July and the end of summer, the main spawning season of this species in Exmouth Gulf is between August and October. Approximately one month after mating, female prawns will release the fertilised eggs, which float and typically hatch within 24 hours (Dall et al. 1990). Active vertical migration during the pelagic larval stage, in combination with water currents, is the most probable method transporting post-larvae to the inshore nursery areas (Penn, 1975; Dall et al. 1990).

As the larval development continues through the protozoea, mysis and postlarvae stages, predators are responsible for high mortality rates of the larvae. If by this time the larvae have drifted to a suitable nursery area (e.g. beds of seagrass and algae), they will settle as post-larvae two to four weeks after eggs are released from the females (Dall, et al 1990; Liu & Loneragan, 1997). If settlement occurs in unsuitable habitats, they are likely to perish.

Juvenile brown tiger prawns occupy shallow waters with seagrass and algal communities, which form the main juvenile habitat for this species (Kenyon, Loneragan, & Hughes, 1995). In Exmouth Gulf, a main migration of juvenile prawns into deeper, more offshore waters occurs during late summer and autumn of each year, after spending approximately six months in the nursery areas (Penn 1980). Prawns move by either walking or swimming, however, the speeds recorded during migration are unlikely to be achieved by walking (Dall et al. 1990).

As pre-adults, brown tiger prawns migrate out of the nursery areas into deeper waters to spawn. Adult brown tiger prawns are generally found over mud or sandy mud substrates in coastal waters less than 30 m depth, however, have been recorded as deep as 200 m (Grey et al. 1983). Most spawning females are found in water 13 – 20 m deep (Penn 1988; Penn et al. 1995).

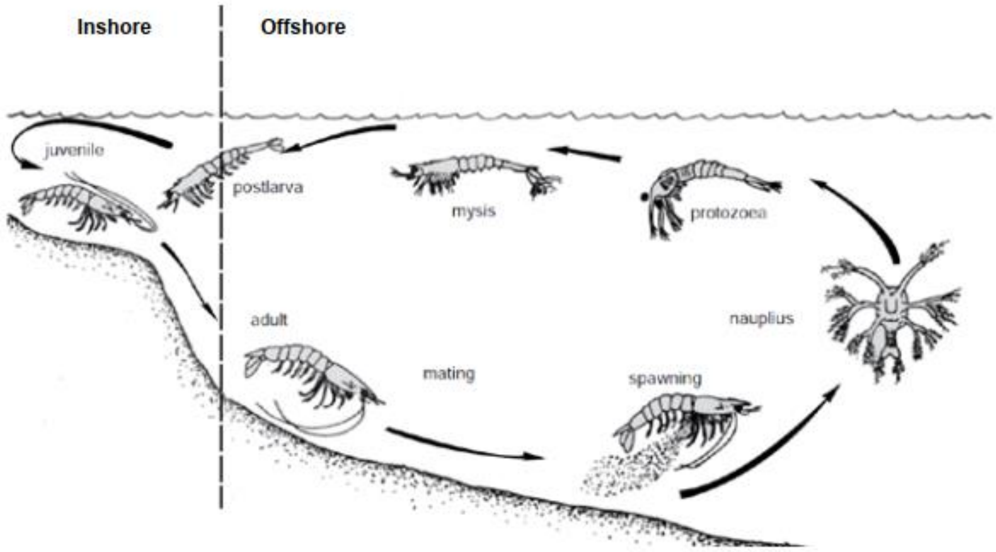


Figure 2-7 Life cycle of a penaeid prawn (modified from NSW Department of Industry and Investment 2010)

2.2.2 Western King Prawns

The western king prawn (*Penaeus latisculcatus*) is a decapod crustacean of the family Penaeidae and is widely distributed throughout the Indo-West Pacific region (Grey et al. 1983). Within Australian waters, this species occurs from South Australia, WA, Northern Territory, Queensland and down the east coast to northern New South Wales (Grey et al. 1983). The species is easily distinguished by its distinctive bright blue legs and tail as shown in Figure 2-8.

Figure 2-8 The western king prawn. Illustration © R. Swainston (www.anima.net.au)

The western king prawn is a fast-growing species that grows to a maximum size of 20 centimetres (cm) and is a highly fecund species, reaching sexual maturity at six to nine months. Western King prawns spawn throughout the year, with a peak spawning period from May to October. The life cycle characteristics of western king prawns closely resemble those described above for brown tiger prawns.

As with other penaeid prawns, western king prawns undertake a migration from nursery areas to deeper, more offshore waters to spawn. This migration, which is likely to occur in response to either biological cues, such as size, and/or some change in their environment (such as rainfall, salinity, currents or temperature).

Post-larval and juvenile western king prawns can be found inshore on shallow tidal flats with sand or mud sediments, which are often backed by mangroves (Penn & Stalker 1979; Kangas & Jackson, 1998). Because there is very little freshwater input, such inshore areas can have salinities higher than seawater (i.e. hypersaline waters). The juveniles of western king prawns prefer this habitat, unlike most other prawn species, which prefer estuarine conditions where seawater is diluted by freshwater.

Juvenile western king prawns spend about three to six months in the nursery grounds before they reach maturity and migrate offshore, entering the trawl fishing grounds (Penn & Stalker 1979). Western king prawns reach maturity at six to seven months of age, at a size of around 25 mm carapace length (CL).

2.2.3 Blue Endeavour Prawns

Blue endeavour prawns (Metapenaeus endeavouri) are a secondary target species whose distribution partly overlaps with that of brown tiger and western king prawns and are caught when fishers are targeting these two species. Blue endeavour prawns are restricted to northern Australian waters between northern New South Wales and Exmouth Gulf in WA (Grey et al. 1983) and are generally found in coastal waters down to approximately 50 m in muddy or sand/mud substrates. They are considered more resilient to fishing pressure due to their smaller size and lower catchability, as well as the lower level of targeting compared to the other target species (Kangas, et al. 2006).

Endeavour prawns are believed to spawn all year round and have a similar life cycle to brown tiger and western kings prawns. Post-larvae and juvenile endeavour prawns are most commonly found in seagrass beds and spend only a short time in nursery areas. Mature endeavour prawns are generally found in coastal waters down to approximately 50 m in muddy or sand/mud substrates.

3 MODELLING PACKAGE

3.1 MIKE Modelling Package

The DHI MIKE modelling package has been used for this project. MIKE is an industry standard software package regularly used for hydrodynamic simulations. The DHI MIKE FM Hydrodynamic model (HD) has been used. It is a general modelling system for simulation of flows in oceans, estuaries, bays and coastal areas. The model simulates unsteady three-dimensional water flows driven by density variations, bathymetry as well as external forcing from meteorologic influences, tide, ocean current and river inflows.

The DHI MIKE FM Hydrodynamic model (HD) can be coupled with various modules and for this study, it was coupled with the agent-based modelling module (ABM Lab). ABM Lab is used for advanced simulations of behaviour and states of individuals or particles (which act as the agents driving aquatic ecosystem dynamics). In this case the agents are prawns, and their life cycle movements were modelled.

The purpose of the ABM was to understand the percentage of the total prawn population that aggregate in Urala Creek South and to quantify the percentage of the population that would be impacted by the intake and outfall.

3.2 Model Mesh

The model is built on an unstructured flexible mesh and uses a finite volume solution technique. Horizontally, the mesh is comprised of triangle and quadrilateral elements. This approach enables variation of the horizontal resolution of the mesh within the model area and tailoring of finer mesh in selected sub-areas. The regional model mesh is displayed in Figure 3-1.

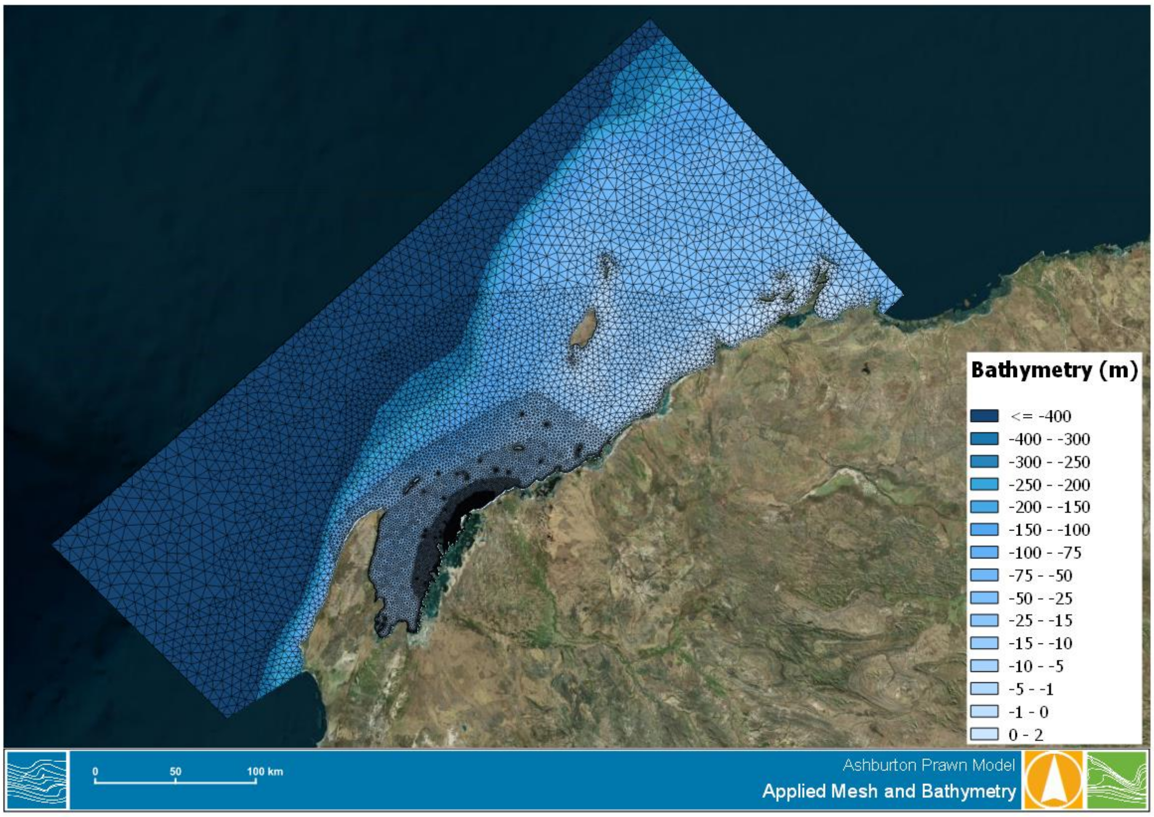


Figure 3-1 Regional Model Mesh

3.3 Hydrodynamic Inputs and Parametrisation

3.3.1 Simulation Length

The model was simulated for a total of 27 months from July 2017 to October 2019. This was because active spawning was modelled for 12 months, and a sufficient amount of time was required to capture any residual prawn movements as they made their way back to the spawning grounds during offshore recruitment. The 2017-2019 period was selected as it was found to have average climatic conditions and allowed for some overlap with the data collected in Urala Creek in 2019. Wind conditions during the modelled period are shown and compared to long term conditions in Figure 3-2.

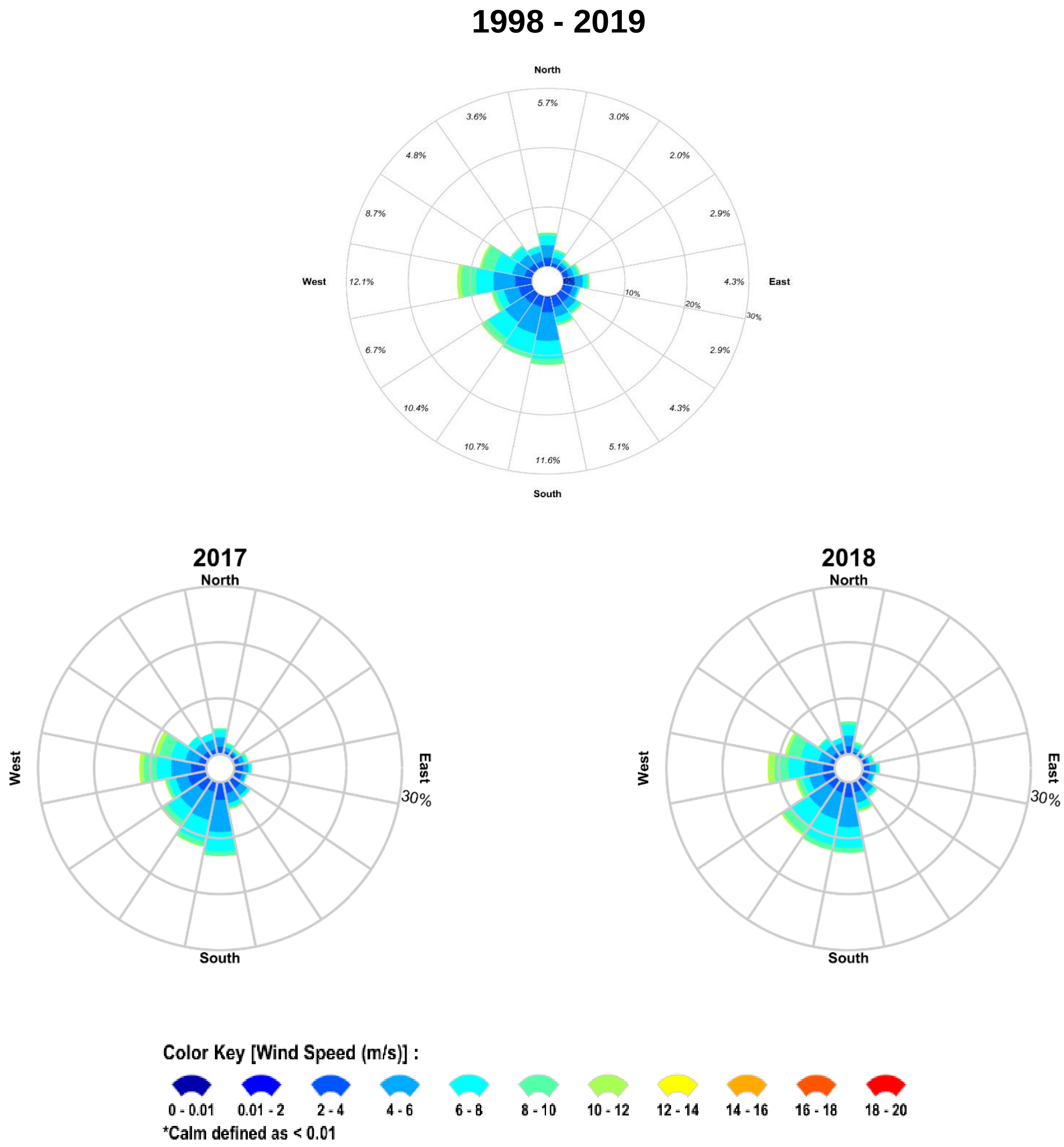


Figure 3-2 Wind conditions during modelled period

3.3.2 Bathymetry

Model bathymetry and topography were derived from a range of sources. A description of each data source is provided below:

- RPS DEM: coarse offshore 200 m gridded Digital Elevation Model (DEM) developed by RPS (2017). Accuracy unknown.
- Geoscience Australia: 250 m resolution gridded bathymetry to fill offshore data gaps not covered by RPS data (not shown on image). Varying degrees of accuracy depending on the region.
- WorldDEM DTM: 12 m-resolution DEM for nearshore areas.
- Fugro LiDAR: 1 m-resolution DEM for terrestrial areas. Stated accuracy ±0.2 m.
- Fugro Surveys: Single beam hydro surveys in Urala Creek North and Urala Creek South. In nearshore waters, transects were completed 200 m apart, and further offshore transects were 1,000 m apart. This data was converted to a DEM.
- University of Western Australia (UWA) Survey: 25 cm-resolution DEM derived from an underwater autonomous vehicle (UAV) survey of Urala Creek South. No metadata provided but accuracy estimated to be ±0.2 m.
- UWA Single Beam Survey: Single beam survey at Locker Point/Jetty site. No metadata provided; accuracy unknown.

3.3.3 Eddy Viscosity/diffusivity

Sub-grid scale horizontal eddy viscosity was parameterised as a function of the local grid resolution using a Smagorinsky formulation. This expresses the effects of sub-grid scale turbulence by an effective eddy viscosity related to a characteristic length scale and local spatial current variations.

3.3.4 Bed Roughness

A bed resistance map was developed in accordance with intertidal and terrestrial features such as mangrove habitats (see Table 3-1). It was used as a key parameter to calibrate tidal levels.

Table 3-1 Roughness Values

Land Use/Topographic Description	Manning's "n"
Offshore	0.03
Sandy/Beach Areas	0.05
Salt Flats	0.05
Algal Mats	0.06
Light Vegetation	0.06
Heavy Vegetation	0.09
Mangrove	0.12

3.4 Boundary Conditions

3.4.1 Water Levels

The model was driven by a spatially variable water level at its open boundaries which takes account of both tidal and subtidal components. Water levels were modelled as follows:

- Tidal levels were extracted from a Global Tide Model developed by DTU Space. The model is available on a 0.125° x 0.125° resolution grid for the 10 major constituents in the tidal spectra. The model utilises the latest 17 years' multi-mission measurements from TOPEX/Poseidon, Jason-1 and Jason-2 satellite altimetry for sea level residual analysis. The constituents consider semidiurnal (M2, S2, K2, N20, diurnal (S1, K1, Or, P1, Q1) and shallow water (M4) constituents.
- Subtidal water levels were extracted from the Hybrid Coordinate Ocean Model (HYCOM) global operation model. This is to represent any seasonal variation of water levels in the region.

HYCOM is an operational ocean model system from the US National Oceanic and Atmospheric Administration (NOAA). The model assimilates satellite altimeter observations, satellite and in situ sea surface temperature, as well as available in situ vertical temperature and salinity profiles from XBTs, ARGO floats, and moored buoys. It is a proven product providing high precision hydrodynamic predictions at a global coverage and with a resolution ranging from 1/12-degree world-wide to 1/25-degree at Gulf of Mexico. The model has over 40 vertical layers, with most layers located near the surface to resolve the stratification near surface boundary layer.

3.4.2 Winds

Spatially variable ERA5 winds were applied over the model domain. ERA5 provides hourly estimates of a large number of atmospheric, land and oceanic climate variables. The data cover the Earth on a 30km grid and resolve the atmosphere using 137 levels from the surface up to a height of 80km. ERA5 includes information about uncertainties for all variables at reduced spatial and temporal resolutions.

Quality-assured monthly updates of ERA5 (1959 to present) are published within 3 months of real time. Preliminary daily updates of the dataset are available to users within 5 days of real time. ERA5 combines vast amounts of historical observations into global estimates using advanced modelling and data assimilation systems.

3.5 Model Calibration

Model calibration consisted of an iterative process of adjusting modelling parameters to arrive at a reasonable comparison between modelled data and recorded measurements. These parameters include but are not limited to bathymetry, boundary and initial conditions, bed resistance and other model constants.

Water levels were calibrated to evaluate model performance in simulating water level variations driven by tides, air pressure, winds and other meteorological and oceanographic forces in the model domain and specifically in the vicinity of the Project site.

The evaluation of model performance measures was undertaken to demonstrate the models' ability to accurately replicate natural processes and characteristics within the region of interest. The following statistical measures were used to assess the models' ability to replicate water levels throughout the system:

- Index of Agreement (IOA) – measure of model predictive skill that ranges from 0 to 1 (Willmott 1981). The highest value of 1 means perfect agreement between model and observation.
- Root mean square error (RMSE) – standard way to measure the error of a model in predicting quantitative data standard deviation of the residuals. Lower values indicate a better fit.

- R^2 - the amount of variance between modelled and observed values. The highest value of 1 means perfect agreement between model and observation.

Tidal data was extracted from the Australian National Tide Tables (ANTT) at several locations throughout the model domain. The extracted ANTT locations in addition to tide gauges installed at the intake and outfall are shown in Figure 3-3. The data from these gauges was compared to the modelled water levels for the calibration.

Figure 3-3 Tide gauge locations

The statistical analysis is summarised in Table 3-2. Good agreement was achieved at all locations as the IOA values were all greater than 0.95. The poorest calibration result was achieved at the intake location which had an R^2 of 0.89, which still indicates good agreement. The slightly reduced result at this location is due to the complex bathymetry and tidal inundation that occurs in the small creek. Despite this, the model is still considered to be performing well at the most challenging calibration location.

Timeseries plots of modelled vs measured water levels for the calibration period are provided in Figure 3-4. These support the statistical analysis and show good agreement at all sites.

Table 3-2 Statistical Calibration

	R^2	RMSE	IOA
Exmouth	0.98	0.07	0.98
Learmonth	0.95	0.14	0.98

	R^2	RMSE	IOA
Onslow	0.98	0.08	0.98
Thevenard Island	0.99	0.05	0.99
Y Island	0.98	0.07	0.99
Intake	0.89	0.15	0.96
Outfall	0.96	0.09	0.98

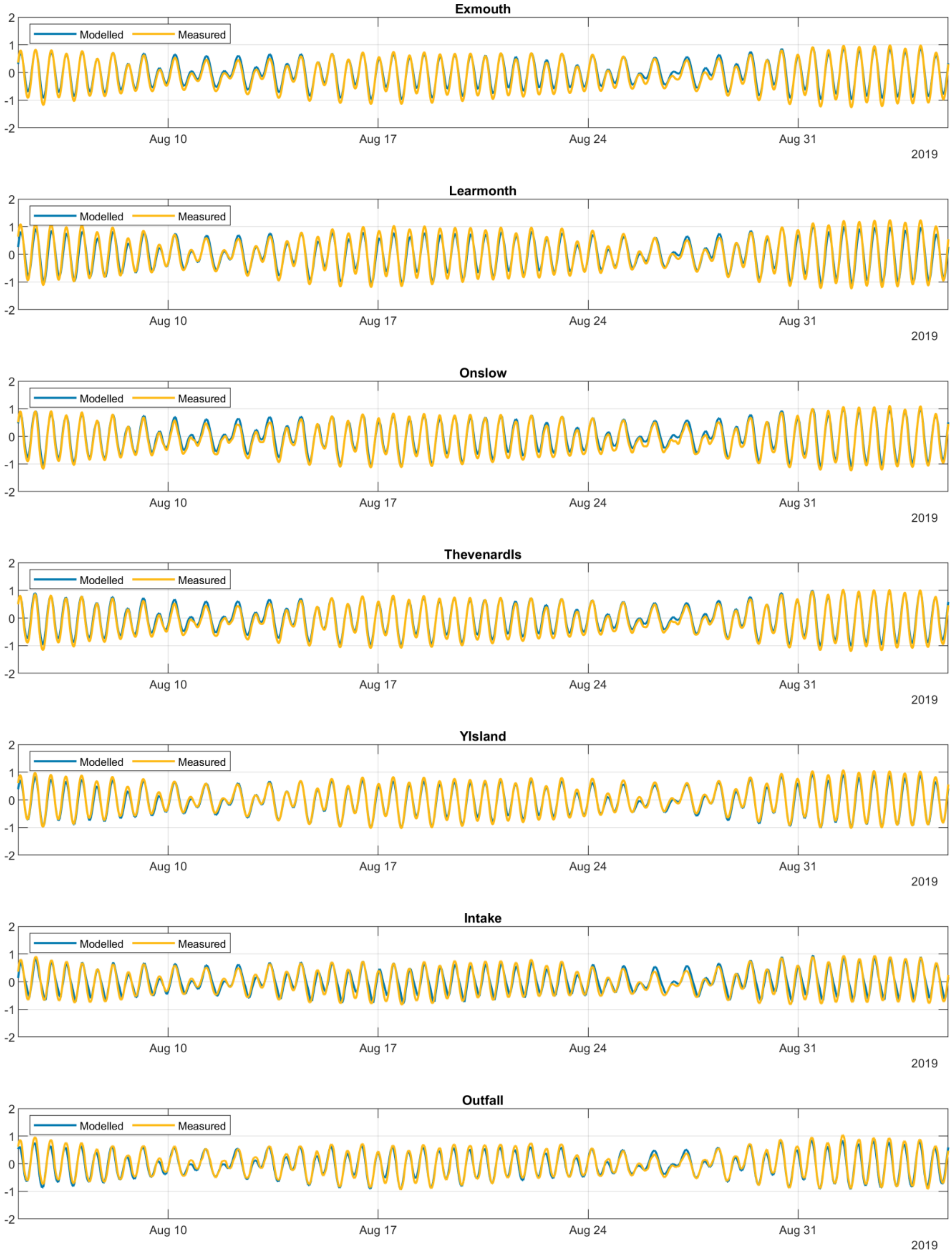


Figure 3-4 Modelled vs measured water levels

3.6 ABM Equations and Variables

This section describes the equations used to calculate some of the time varying variables within the model.

3.6.1 Carapace Length

A Von Bertalannfy growth model, which is the most commonly used growth curve in fisheries, was used to calculate each species growth throughout the ABM simulation. The follow formula was taken from Chavez (1972) and applied within the model:

$$L = L_{\infty}[1 - e^{-k(t-t_o)}]$$

Where:

L = Length at age t in mm

L_{∞} = Average maximum length

k = Constant, proportional to catabolic rate

t = Age in months

t_o = Theoretical adjustment parameter, which expresses the age when the length is zero

Each species had different parameters applied based on advice from key project advisors and stakeholders, particularly Dr Neil Loneragan from Murdoch university. Adopted parameters are tabulated in Table 3-3 which represent the average across sex for each species.

Figure 3-5 to Figure 3-7 show the modelled prawn growth for each species.

Table 3-3 Length equation parameters

	Brown Tiger	Western King	Blue Endeavour
L_{∞}	40	50	36.2
k	-0.21	-0.168	-0.197

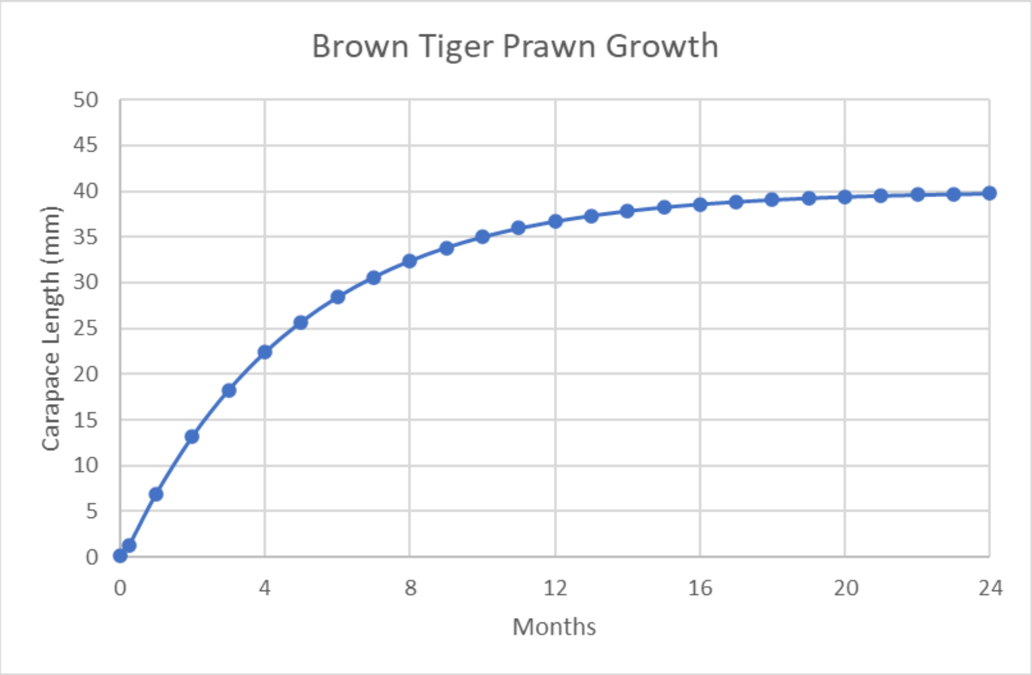


Figure 3-5 Brown tiger prawn growth

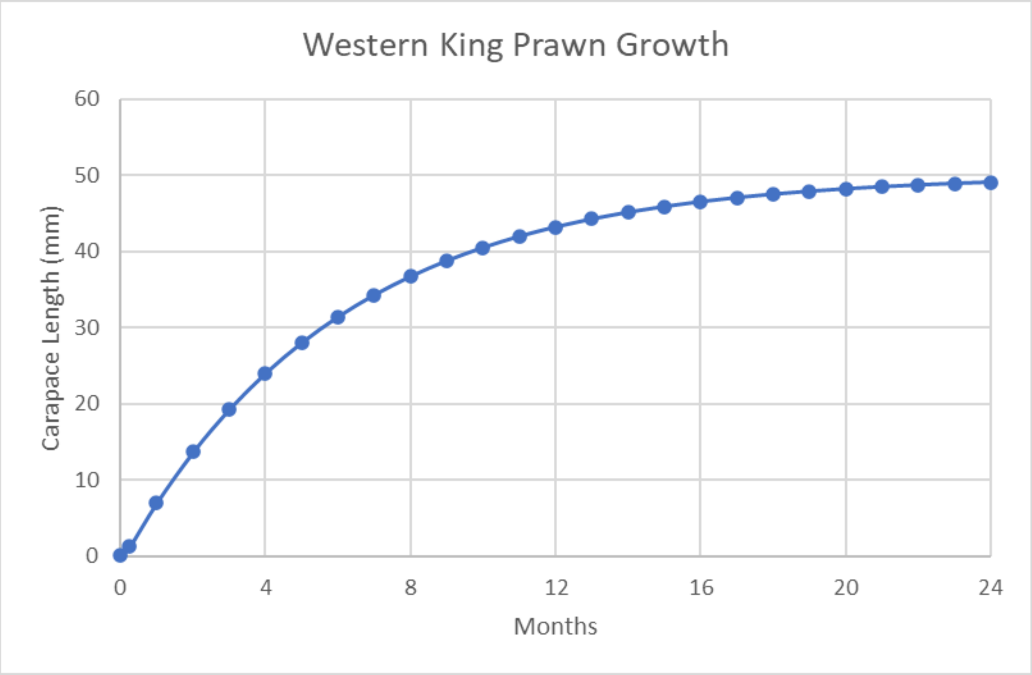


Figure 3-6 Western king prawn growth

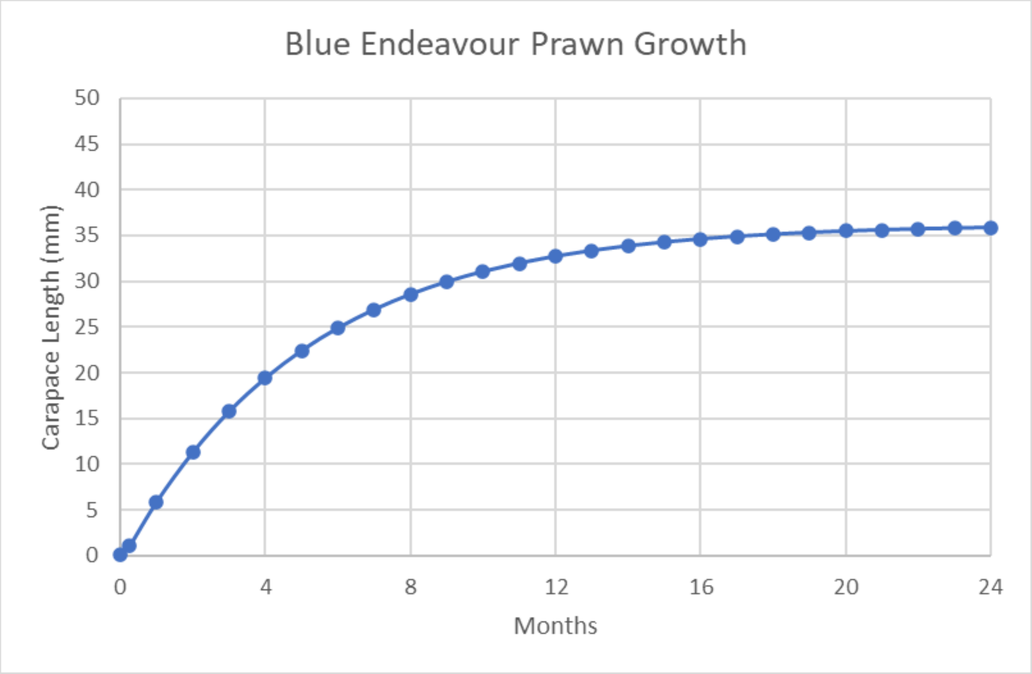


Figure 3-7 **Blue Endeavour Prawn Growth**

3.6.2 Mortality

Mortality was discussed as key variable of interest and was sensitivity tested extensively. A mortality equation that was dependant on growth was adopted from Yimmin et al (2005):

$$M_t = aL_t^{-b}$$

Where:

M_t = mortality rate at week t

t = age in weeks

L_t = Carapace length at week t

t, a, b = parameters defining how mortality changes within the population

As mortality is largely due to predation, environmental factors were not considered. A random portion of the population died each week based on the M_t calculation.

During sensitivity testing, it was found that the inclusion of mortality did not influence the percentage of the surviving population that enters Urala Creek South, which is the area of interest. It also required a significantly larger number of agents to be modelled and was much more computationally demanding. It was decided that because mortality did not influence study outcomes and due to the additional computational demands, it would not be included in the final assessment simulations.

3.7 ABM Inputs

This section describes some of the ABM inputs that control the way the prawn life cycle is modelled.

3.7.1 Spawning

Each species has a different spawning area that was provided by DPIRD (see Figure 3-8). During each full moon, from July 2017 to June 2018, 1,000 prawns were released in the spawning areas per species. The spawning rate was constant throughout the year for each species, and this results in a total population of 12,000 prawns.

During sensitivity testing, 1,000 prawns per month were found to be an optimal number that ensured good spatial distribution throughout the Gulf, without comprising computational run times. Increasing the number of prawns did not result in a higher proportion of prawns reaching Urala Creek South.

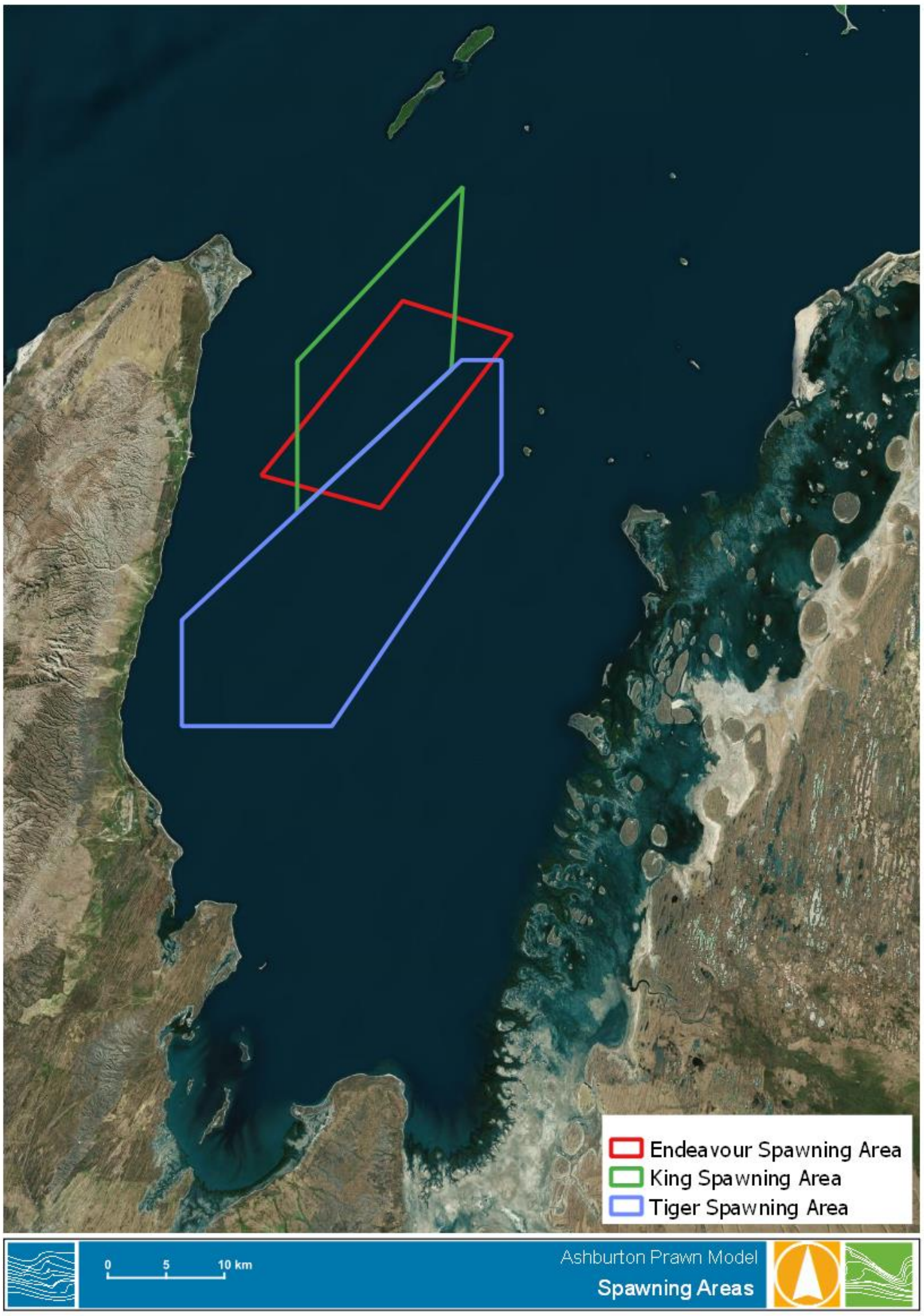


Figure 3-8 Spawning area by species (Source: DPIRD)

3.7.2 Habitat

Seagrass beds are important habitat for all prawn species, and all species are dependent on this habitat when they are in the nearshore. It was imperative that seagrass habitat throughout Exmouth Gulf be included in the model. Traditionally habitat mapping throughout Exmouth Gulf has been sparse due to its remote location and expansive size. Scott Evans from DPIRD undertook a research project to assess using a novel remote sensing approach to map seasonal aquatic vegetation as macroalgae, and provided the data for input into the ABM (see Figure 2-4). The March macroalgae mapping was applied within the model to represent the wet season from January to July, and macroalgae habitat during the dry season from August through to December was represented by the August mapping. The data provided has an overall accuracy of 82% and 78% for March and August respectively.

3.7.3 Intake and Outfall

The impacts of the intake and outfall (bitterns discharge) were modelled comprehensively in the *Coastal and Marine Modelling* report (Water Technology, 2021). This section provides a summary of how these model results were incorporated into the ABM.

For the outfall, a Moderate Ecological Protection Area (MEPA) was proposed in the region where the median salinity level of the modelled bitterns discharge plume is within the 95th percentile of natural background salinity. This equated to a buffer of 50 m in all directions. When assessing the worst-case scenario during November (when the discharge is highest), the MEPA was predicted to extend about 80 m on the eastern side and about 100 m on the western side of the diffuser. In a cross-shore direction, the MEPA extent was less than 30 m from the end of the jetty, as shown in Figure 3-9. Within the ABM, a 100 m buffer was applied around the entire jetty, and if a prawn entered the buffer zone it was considered dead.

Figure 3-9 Modelled LEPA and MEPA Zones (November, Worse Case, Maximal Discharge)

The intake was implemented as a negative source point with a constant inflow rate of 10.97 m^3/s, which represented the worst-case month during November. Modelling has been configured on a conservative basis by representing the seawater intake as continuous pumping during the worst-case month.

The intake modelling found current speeds were increased by 0.3 m/s 30 m upstream and downstream from the intake. Prawns can swim up to 0.3 to 0.6 m/s depending on their size. For conservative modelling purposes, an increase of 0.3 m/s was considered to be stronger than a prawns swimming ability, and would result in their advection into the intake pipe. Consequently, within the ABM a 30 m buffer was applied around the intake pump site. Furthermore, as part of sensitivity testing two larger buffers of 50 m and 100 m were also modelled. In order to present the most conservative result, a buffer of 100 m was applied with the ABM, whereby if prawns came within 100 m of the intake, they would be advected into the intake and lost. This is considered extremely conservative as we deliberately overestimated the intake impact zone by 70 m.

3.8 Prawn Movements

The ABM package allows the coupling of multiple "if" statements which control the horizontal and vertical movement of the agents, in this case prawns. The three key life stages to modelled are larvae, post-larvae and juveniles. The following movements were based on input from the stakeholder working group and modelling practices in Condie et al. (1999):

- Larvae – during the first 8 days, the larvae move with the net current and have no horizontal swimming ability, but vertically move through the water column so that they are on the seabed during the day and at the surface at night to simulate the diel migration.
- Post-larvae – 9 days after spawning, the following movements play:
    - If they are in offshore waters (water depth between 1.5 and 20 m), post-larvae will move with the net current during the flood tide, and bury themselves during the ebb tide. The post-larvae can sense the change in hydrostatic pressure and use the flood tide to move into nursery areas;
    - If they are inshore (water depth < 1.5 m), they will only be marginally influenced by tidal flows; and
    - When their carapace length reaches 10 mm, they will actively swim to macroalgae and remain close to the seabed, whilst they are marginally influenced by tidal flows.
- Juvenile - When their carapace length reaches 15 mm, they begin to actively swim toward their spawning offshore areas. During this time, they move to the seabed during the day where they walk around uninfluenced by tidal currents and, and swim to the surface at night.

All movements after 9 days were coupled with a random walk process, to simulate the natural variability of each prawn swimming uniquely.

The movements built into the model were supported by the stakeholder working group.

4 MODEL RESULTS

4.1 Urala Creek South

The modelling was assessed over a 12-month spawning period to estimate the percentage of the prawn population that spend time in Urala Creek South as post-larvae and juveniles. The modelling found that of the three species modelled, the western king prawns had a higher proportion of their population end up in Urala Creek South. This is because their spawning grounds are the most northern and closest Urala Creek. Brown tiger prawns, which have the largest spawning area that also extends the furthest south, have the smallest population percentage in Urala Creek South. Modelled results are shown in Table 4-1.

Table 4-1 Percentage of annual population in Urala Creek South

	Brown Tiger	Western King	Blue Endeavour
Population in Urala Creek South	0.1%	1.2%	0.6%

Figure 4-1 to Figure 4-3 show the number of individual prawns that enter Urala Creek South over the model simulation. It should be noted that spawning started at the first full moon in July 2017, however no prawns reach Urala Creek South until September at the earliest. It takes on average two to four weeks for prawns to reach nursery ground, however during April to September winds are generally weaker and can often be from the north and south which can push post-larvae away from Urala Creek. During October to February, winds are more from the west to southwest, which pushes post-larvae further toward the coast and Urala Creek. The plots show that the largest influx of post-larvae occurs during this time from December to February.

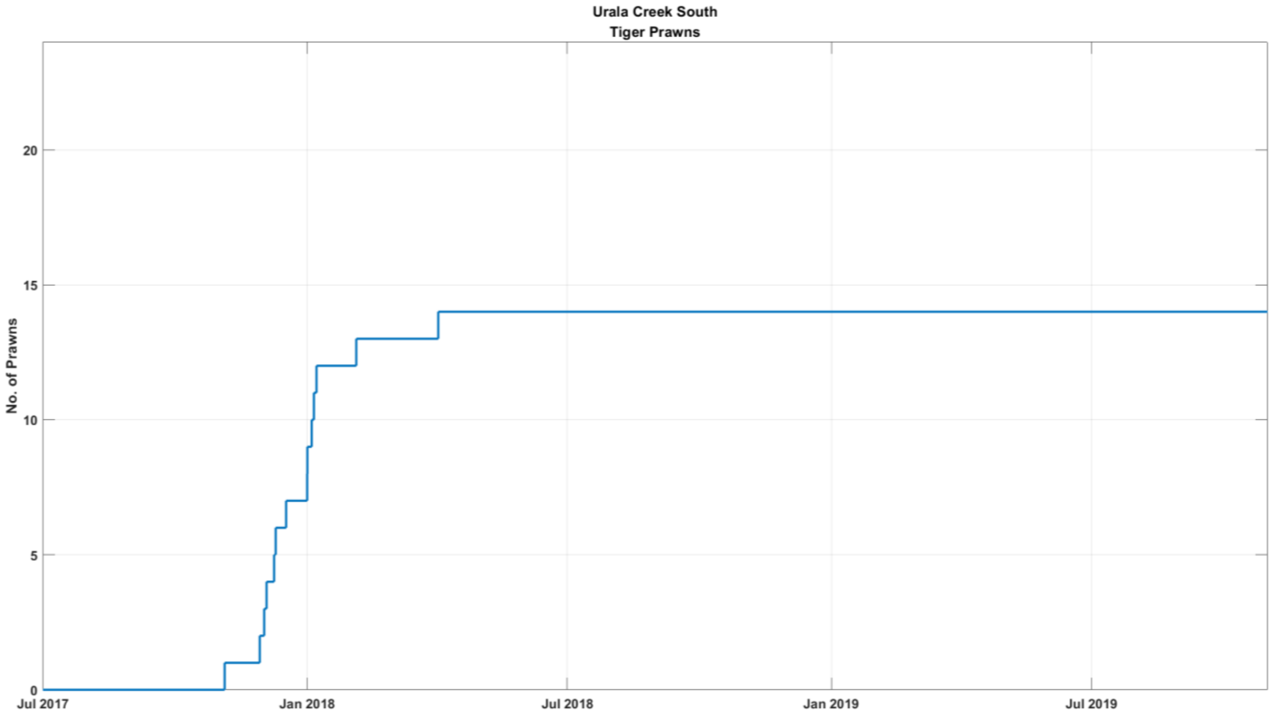


Figure 4-1 Number of brown tiger prawns that enter Urala Creek South

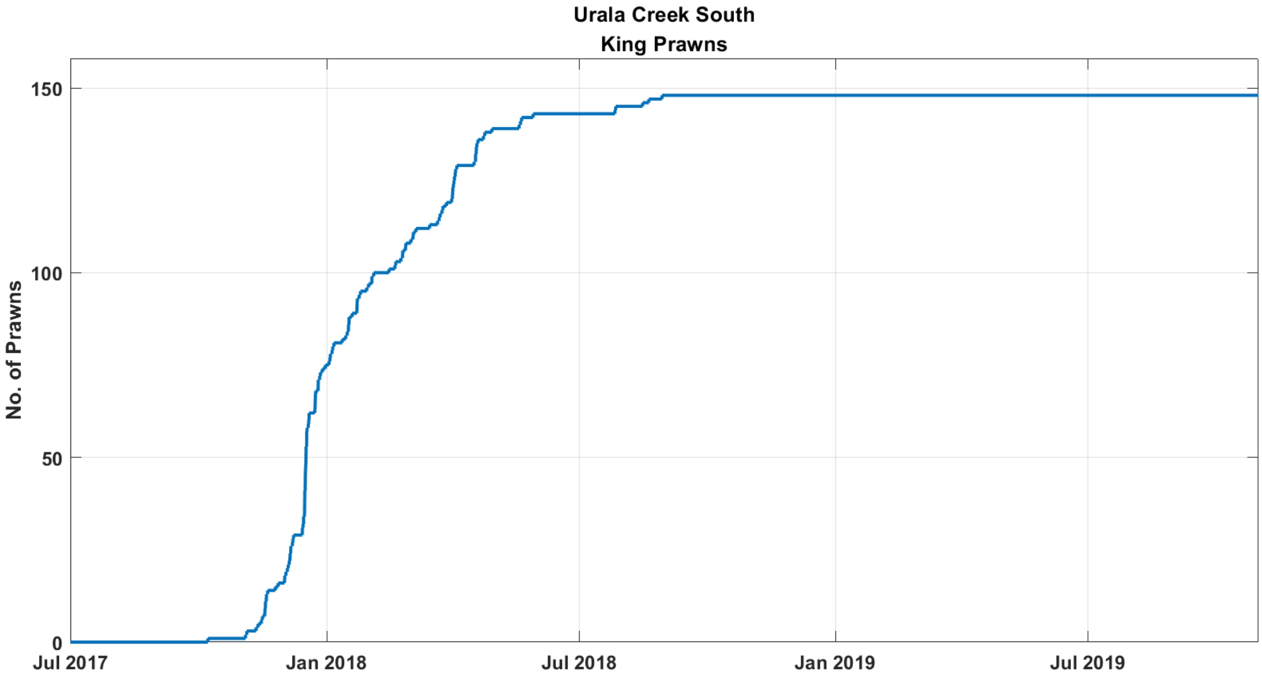


Figure 4-2 Number of western king prawns that enter Urala Creek South

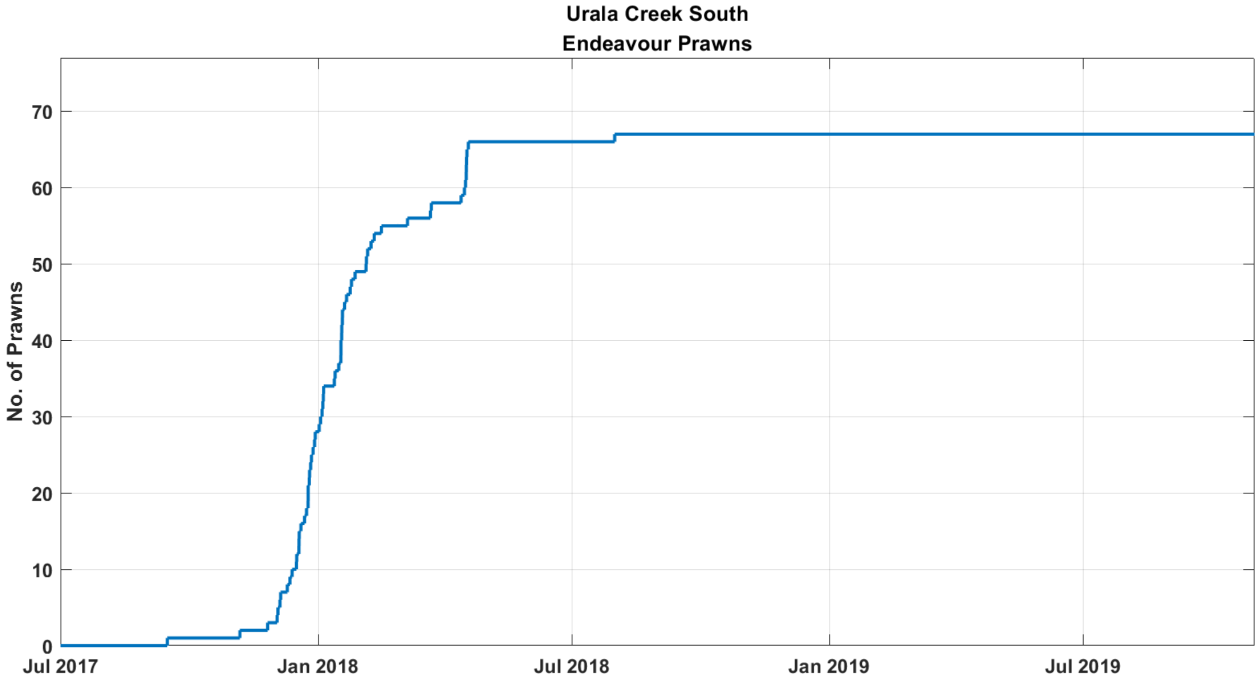


Figure 4-3 Number of blue endeavour prawns that enter Urala Creek South

4.2 Impact Assessment

The intake and outfall were incorporated into the model as described in Section 4.2. The results of the annual percentage of the population lost are presented in Table 4-2. Based on the analysis in Section 4.1, which found western king prawns to be more prevalent in Urala Creek South, it is not surprising that this species also had the greatest number of prawns lost to the outfall and intake. Very few prawns made it to Locker Point where the outfall is located, and even less made it to the outfall location which resulted in very little prawn loss at the outfall.

Overall the modelling exercise found that the intake and outfall were not expected to significantly impact prawn fishery stock in Exmouth. The most impacted species is the western king prawn, which could see a 0.08% annual reduction in the prawn population, followed by blue endeavour (0.05%) and brown tiger (0.01%).

Table 4-2 Percentage of annual population lost

	Brown Tiger	Western King	Blue Endeavour
Outfall	0.0%	0.02%	0.0%
Intake	0.01%	0.06%	0.05%
Total (outfall + intake)	**0.01%**	**0.08%**	**0.05%**

5 SUMMARY

A collaborative exercise was undertaken between government, industry and academic specialists, to assist in the development of an ABM suitable to quantify the potential impacts to three prawn species of the Ashburton Salt Project. As part of the process, a regional hydrodynamic model was developed and calibrated, and the ABM development was undertaken. The stakeholder working group was involved in the ABM development with several workshops where the inputs, variables and movements were recommended and reviewed.

Upon completion of the ABM development, the potential impacts of the bitterns discharge and seawater intake on three prawn species were quantified. Overall the modelling exercise found that the intake and outfall were not expected to significantly impact the prawn fishery in Exmouth Gulf. The most impacted species were western king, which could see an 0.08% annual reduction in the prawn population, followed by blue endeavour (0.05%) and brown tiger (0.01%).

This study has been a collaborative effort with extensive stakeholder engagement. We would like to thank the following participants for their highly valuable contributions:

- Mervi Kangas, DPIRD;
- Scott Evans, DPIRD;
- Jim Penn, Fisheries Research and Management Consultant;
- George Kallis, MG Kallis; and
- Neil Lonergan, Murdoch University.

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