Options to mitigate potential starvation of penguins during the Westport dredging campaign – review and recommendations

Theme: Apex Predators and Iconic Species

WAMSI Westport Marine Science Program

WESTERN AUSTRALIAN MARINE SCIENCE INSTITUTION

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WAMSI WESTPORT MARINE SCIENCE PROGRAM

ABOUT THE MARINE SCIENCE PROGRAM

The WAMSI Westport Marine Science Program (WWMSP) is a $13.5 million body of marine research funded by the WA Government. The aims of the WWMSP are to increase knowledge of Cockburn Sound in areas that will inform the environmental impact assessment of the proposed Westport development and help to manage this important and heavily used marine area into the future. Westport is the State Government's program to move container trade from Fremantle to Kwinana, and includes a new container port and associated freight, road and rail, and logistics. The WWMSP comprises more than 30 research projects in the biological, physical and social sciences that are focused on the Cockburn Sound area. They are being delivered by more than 100 scientists from the WAMSI partnership and other organisations.

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1 Options to mitigate potential starvation of penguins during the Westport dredging campaign- review and recommendations.

Determining the diet, causes of mortality, foraging habitat and home range of Little Penguins using Cockburn Sound: Objective 4

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Project
Determining the diet, causes of mortality, foraging habitat and home range of Little Penguins using Cockburn Sound

Date
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Executive Summary

This review proposes strategies to mitigate Little Penguins potentially starving from impacts associated with dredging on penguin fish prey, important fish habitat or penguin foraging habitat during the dredging campaign associated with the construction of a port in Cockburn Sound, Western Australia. However, currently there are only concept plans for both the proposed port footprint and the location of the port, and no definitive information on the timing or duration of construction, the timing or duration of dredging, and the methods used for dredging and construction. It is known that dredging will be necessary to 1) create a new access channel, currently proposed to be parallel to the existing channel across Parmelia and Success banks in Owen Anchorage, 2) widen and deepen the existing channel, 3) create shipping channels across the Kwinana Shelf, and 4) create a harbour on the Kwinana Shelf. Approximately 10 million cubic metres of sand will be removed from the Kwinana Shelf, and 7 million cubic metres from the Parmelia and Success bank channels. Without detailed information for the dredging and construction, it is only possible to propose general principles on the impact of these programmes both directly on penguins and indirectly on them, via impacts on the fish they prey on.

Little penguins are a listed marine species under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). The northern-most colonies are located in the Perth metropolitan region, on Penguin, Garden and Carnac islands. Little Penguins in the Perth metropolitan region were assessed as having the highest relative threat and the highest conservation value of all marine fauna in the same region (Department of Conservation and Land Management 2003).

Breeding penguins from Garden Island have been found to forage exclusively within Cockburn Sound during both the incubation and chick-guard phase, and the breeding penguins that inhabit the NE side of Penguin Island have been found to typically forage within Cockburn Sound during the incubation period (Cannell 2009, 2016, 2019). The area used during incubation extended from the northern end of the Central Basin south to Mangles Bay, and on the eastern section on the Kwinana Shelf (Cannell 2009). During the guard phase, the penguins almost exclusively used the southern half of Cockburn Sound (Cannell unpubl. data).

Penguins foraging within Cockburn Sound were found to predominantly prey on scaly mackerel (*Sardinella lemuru*), anchovy (*Engraulis australis*) and pilchard (*Sardinops sagax*). To a lesser extent they preyed on sandy sprat (*Hyperlophus vittatus*), blue sprat (*Spratelloides robustus*), silverbelly

(*Parequula melbournensis*), hardyheads (*Atherinomorus vaigiensis*) and sea mullet (*Mugil cephalus*) (Cannell unpubl. data). Starvation is the second-most prevalent cause of mortality of the local Little Penguins (Cannell et al. 2016a), and from July-September 2021, at least 12 of 27 penguins found dead in WA (mostly in the Perth metropolitan region) were emaciated. This is at least double the average number to have died from starvation in these months (Cannell et al. 2016a, Cannell unpubl. data). This event coincided with reduced salinity, increased tannins, chlorophyll blooms and turbidity in Cockburn Sound from unprecedented recorded winter rainfall in many areas across the Greater Perth region and associated very high levels of Swan River discharge (Pattiaratchi and Thomson 2021). This finding indicates penguin survival in this area can be threatened by instances of environmental disturbance.

The simplest and most effective method to reduce the likelihood of direct impacts of dredging on Little Penguins is to **not** conduct the dredging campaign during the breeding season and the pre-moult period (from April-January).

To prevent significant impacts on the Penguin population from dredging, there are two major options available:

1) reduce impacts of dredging on penguins and their fish prey and their important habitats
    a. Avoid dredging during breeding and pre-moult periods (April-Jan)
    b. Employ best practice dredging management to control the extent, duration and intensity of the dredge plume on penguins and their important prey species and habitats
2) aggregate fish in an area not impacted by dredging but within the typical home range of the penguins during the breeding season.

To minimize the impacts of dredging on coastal fish, it is suggested that sediment concentrations should be kept below critical thresholds (e.g. 44mg/L and for less than 24 hours (Wegner et al. 2018) and/or apply seasonal limits on dredging, based on known spawning and recruitment times (Wegner et al. 2018). However there is limited information on the timing of spawning and recruitment for the major prey of penguins in Cockburn Sound, and even which habitats are important for them (although information from WAMSI Project 4.2.1 will help fill these knowledge gaps). As such, it is not currently possible to recommend seasonal limits or to determine strategies which will limit impacts on important penguin prey habitats.

Fish aggregating devices (FADs) could be used to aggregate fish in areas not impacted by dredging but within the home range of the penguins. However, the dynamics of the fish using FADs can change with time, with respect to both fish stage and species. The success of FADs is dependent on a number of environmental variables.

The deployment of FADs would require 1) input from the Department of Transport 2) input from the Department of Primary Industries and Regional Development; 3) a targeted educational/awareness program; and 4) detailed modelling of the likely turbidity in Cockburn Sound associated with the dredging to avoid placement of the FADs in areas with turbidity greater than the thresholds to reduce impacts on fish.

2 Introduction

The purpose of this review is to determine potential strategies to mitigate the likelihood of penguins starving during the dredging campaign necessary for the construction of a proposed new port development in for Cockburn Sound. However, currently plans for both the proposed port footprint and the location of the port are still being developed, and no definitive information on the timing or duration of construction, the timing or duration of dredging, and the methods used for dredging and construction. It is known that dredging will be necessary to 1) create a new access channel, currently proposed to be parallel to the existing channel across Parmelia and Success banks in Owen Anchorage, 2) widen and deepen the existing channel, 3) create shipping channels across the Kwinana Shelf, and 4) create a harbour on the Kwinana Shelf. Approximately 10 million cubic metres of sand will be removed from the Kwinana Shelf, and 7 million cubic metres from the Parmelia and Success bank channels. Without further detailed information for the dredging and construction, it is only possible to propose general principles on the impact of these programmes both directly on penguins and indirectly on them, via impacts on the fish they prey on. Therefore, this review firstly gives background information on the ecology of Little Penguins on Penguin and Garden islands (given that penguins from both colonies feed within Cockburn Sound). Secondly, it briefly describes the general impacts of dredging on fish and their habitats (note that impacts of dredging on fish species and habitats within Cockburn Sound, and the determination of important habitats for fish species within Cockburn Sound are outcomes of projects 7.1, 7.3, 4.4, 2.2, 2.4 and 4.2.1 respectively). Thirdly, the strategies that could be used to prevent Little Penguins that forage within Cockburn Sound from potentially starving during the dredging campaign of the construction of the new port are described.

3 Ecology of Little Penguins on Penguin and Garden islands

Little penguins are a listed marine species under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). In Western Australia, Little Penguins are found on offshore islands, and their distribution extends from Carnac Island, 10 km southwest of Fremantle, through to the Recherché Archipelago, i.e. within the South-West Marine Bioregion. Within this region, Little Penguins were identified as a regional priority for conservation (DSEWPaC 2012). The northern-most colonies are located in the Perth metropolitan region, on Penguin, Garden and Carnac islands. Little Penguins in the Perth metropolitan region were assessed as having the highest relative threat and the highest conservation value of all marine fauna in the same region (Department of Conservation and Land Management 2003).

Various aspects of the ecology of Little Penguins on both Penguin Island (PI) and Garden Island (GI) have been extensively researched. The penguins from PI and GI are genetically similar, but distinct to even those in the south-west (Vardeh 2015, Cannell et al. 2020). They have a protracted breeding season on both islands, with eggs laid any time from April- December (Wooller et al. 1991, Cannell 2004, Cannell et al. 2012). Peak of egg lay on both islands varies within and between years. A clutch of 2 eggs is generally laid, and two clutches can be laid in a season. Both parents share incubation and chick rearing. The eggs are incubated for approximately 5 weeks with the parents swapping every 3-12 (or more) days (Chiaradia and Kerry 1999, Cannell 2016, Cannell 2019). Once hatched, the parents take turns guarding the chick/s, swapping every 1-2 days (Chiaradia and Kerry 1999, Cannell 2018, 2019). The guard phase extends for 2-3 weeks, after which both parents forage during the day and return in the evening to feed the chicks.

Little Penguins prey on small baitfish and cephalopods, and are regarded as a generalist predator. Penguins foraging within Cockburn Sound were found to predominantly prey on scaly mackerel

(*Sardinella lemuru*), anchovy (*Engraulis australis*) and pilchard (*Sardinops sagax*). To a lesser extent they preyed on sandy sprat (*Hyperlophus vittatus*), blue sprat (*Spratelloides robustus*), silverbelly (*Parequula melbournensis*), hardyheads (*Atherinomorus vaigiensis*) and sea mullet (*Mugil cephalus*) (Cannell unpubl. data).

In a recent study on the causes of mortality of Little Penguins from PI and GI, 25% was due to watercraft injury. The second-most prevalent cause of mortality was starvation (Cannell et al. 2016a). High incidence of starvation was observed in 2011 during the marine heatwave (marine heatwaves are predicted to become more frequent and intense with climate change), in mid-2017, and in mid-2021. More than four times the average number of dead penguins were found in 2011, and most of these were emaciated (Cannell et al. 2019). Twenty-seven dead penguins were found in July-September 2021 in WA (mostly in the Perth metropolitan region), with at least 12 of these being emaciated. This is 10 times the average number of dead penguins found for these months (excluding the large number found in 2011), and at least double the average number to have died from starvation in these months (it is possibly greater given the cause of mortality for a third of the dead penguins has not yet been identified) (Cannell unpubl. data). This event coincided with reduced salinity, increased tannins, chlorophyll blooms and turbidity in Cockburn Sound from unprecedented recorded winter rainfall in many areas across the Greater Perth region and associated very high levels of Swan River discharge (Pattiaratchi and Thomson 2021). This finding indicates penguin survival in this area can be threatened by instances of environmental disturbance.

Other causes of mortality to Little Penguins in the Perth region include the presence of protozoan parasites, notably *Toxoplasma gondii*, with cats the only host of this parasite (Campbell et al. 2021) and overheating (i.e. hyperthermia), particularly during summer breeding (chicks have increased vulnerability to hyperthermia during breeding) and moulting adults (Cannell et al. 2016a). Butyltins have also been found in 52% of the 25 penguins that have been tested for butyltin levels, including in a partially fledged chick that had not been to sea but was still being fed by its parents (Cannell et al. 2016a and b). This suggests that the butyltins were either transferred to the chick within regurgitated prey, or through maternal transfer via the egg. Whilst butyltins can cause abnormal neuronal function, behavioural changes, energy imbalances, morphological changes, apoptosis of cells and the inactivation of enzymes responsible for the detoxification of environmental pollutants, their role in the mortality of the penguins is not currently known (Cannell et al. 2016b and refs within).

Cumulative impacts on Little Penguins in the Perth region include climate change, increase boat traffic, further development in Cockburn Sound (WAMSI 2019a), and increased turbidity from development and boat traffic. Whilst research shows that higher SST in April and May negatively influence breeding outcomes of the **PI** penguins (Cannell et al. 2012), current modelling suggests that elevated SSTs do not influence mortality (Cannell unpubl. data). Climate change impacts on penguins include (but are not limited to) 1) increasing storm severity, impacting access to nest sites by creating vertical walls of sand on beach accesses, 2) high terrestrial temperatures in summer, and 3) increasing SSTs, which affects fish prey abundance and location and ultimately penguin breeding. However, the penguins on GI are less likely to be impacted by these changes as 1) the majority of the access points are directly onto rockwalls, 2) the temperatures within both the rockwall burrows and even the well-shaded nestboxes are much lower (Cannell unpubl. data) than natural and burrow temperatures recorded on PI (Ropert-Coudert et al. 2004, Clitheroe 2020) and 3) in 2011, when SST were elevated, the breeding outcomes of the penguins on GI, albeit lower than average, was almost double than that of the penguins on PI (Cannell et al. 2014). It is likely that scaly mackerel, a tropical species, is present in Cockburn Sound when SSTs increase. Therefore, cumulative impacts of increased boat traffic, developments and turbidity are more likely to impact the penguins on GI than impacts associated with climate change.

Breeding penguins from GI have been found to forage within Cockburn Sound, and the penguins that inhabit the NE side of PI typically foraged within Cockburn Sound, but only during the incubation period (Cannell 2009, 2016, 2019). Prior to breeding, Little Penguins are more likely to be at their nest site one, four and seven weeks before laying (Reilly and Cullen 1981). As some of the penguins in the main colony on GI lay eggs in April, then increased visitation can occur as early as February. However, it is not known where the penguins feed during 1)the pre-breeding stage, 2) just prior to moulting (i.e. premoult), or 3) the period after moulting but before returning to the island for pre- breeding. Moult typically occurs any time from December-February, and premoult occurs for approximately 2 weeks prior to moult. It is also unknown where juveniles forage. Juveniles span an age range of approximately 8 weeks old to 2 or 3 years old. However, they typically do not return to their natal colony, i.e. where they were hatched, until they are 2-3 years old. Therefore, it is not known if juveniles even remain within Cockburn Sound. The breeding success of penguins on GI has consistently been better than that on PI (Cannell unpubl. data), and is related to the close proximity of their feeding grounds and the likely more consistent food supply close to the colony (Cannell unpubl. data). The less energy the penguins have to put into travelling, the better their overall body condition and the more energy available for breeding. Additionally, the potential for fewer impacts on the GI colony related to predicted climate change pressures suggests that the viability of the GI colony is greater than that on PI (Cannell 2012).

Core foraging habitat in Cockburn Sound is dependent on stage of breeding. During incubation, core foraging habitat of penguins from both PI and GI has been found to extend from the northern section of the Central Basin to Mangles Bay in southern Cockburn Sound, and on the eastern section on the Kwinana Shelf (e.g. Cannell 2009, 2018, 2019). During the chick-guard phase, the GI penguins foraged in the southern section of the Sound e.g. in the deep basin, on the Kwinana Shelf and in Mangles Bay (Cannell 2009, Cannell unpubl. data). Due to the lack of historical environmental variables with high spatial and temporal resolution, it has not been possible to determine factors influencing these core foraging habitats. However, recent studies from Little Penguins elsewhere have shown that whilst the home range of Little Penguins comprised of areas with higher Chlorophyll-a biomass and turbidity compared to areas where the penguins were not found, the core foraging habitat had lower Chlorophyll-a biomass and turbidity (Kowalczyk et al. 2015). Additionally, modelling of the breeding performance of penguins on GI in 2021 showed that turbidity was the only environmental variable that significantly negatively influenced breeding (Cannell 2022).The poor breeding performance also coincided with a lack of baitfish presence within the deep basin and Kwinana Shelf (DPIRD pers. comm), and the increased number of penguins dying from starvation. It is likely that the increased turbidity, which is known to reduce fish presence (Wegner et al. 2017 and refs within), affected fish presence in Cockburn Sound, and hence penguin population viability.

Little Penguins, like all seabirds, are visual predators (Cannell and Cullen 1992). Thus, increased turbidity can directly impact the penguins by potentially reducing their ability to forage (Preston et al. 2008), as has been found for great cormorants (*Phalacrocorax carbo*) (Hao 2008). Furthermore, increased turbidity and a disruption of marine food webs from dredging has been proposed to impact the foraging efficiency, survivorship and breeding of penguins (Crawford et al. 2009, Poupart et al. 2017).

It is not only increased turbidity which can increase the likelihood of penguins starving during and after the dredging campaign. Noise from the dredging campaign can also potentially impact penguins both behaviourally and physiologically. There are limited data on the noise levels that impact penguins, but bursts of acoustic energy at 120dB re 1 μPa influenced the behaviour of penguins (Sørensen et al. 2020). How this noise level which influenced penguins is related to the noise emitted from dredging equipment is not known, as the type of dredging equipment to be used in the current proposal has not been identified. Additionally the in-water propagation of dredge sound, and its impact on fauna, is dependent on several factors including water temperature, substrate type, depth of water and duration of sound (WODA 2013) However, projects 7.1 (Baseline soundscape, sound sources and transmission), 7.2 (Hearing sensitivity of Australian sea lions, little penguins, and fish) and 7.3 (Behavioural fish audiogram(snapper and another species) should better inform the likely impacts of dredging noise in Cockburn Sound on the penguins. Generally, impacts of anthropogenic marine noise on a range of marine fauna include:

- physical damage e.g. hearing loss,
- physiological stress e.g. increased heart rate,
- auditory masking,
- spatial deterrence,
- behavioural interruption, and
- signal modification (Slabbekoorn 2012).

It is important to note that hearing is important to penguins, as they rely on auditory cues to identify their chicks and mates, and may use hearing to determine the location of fish schools.

Given that it is likely that the entire penguin colony on GI forages within Cockburn Sound during breeding (Cannell unpubl. data), then the magnitude of the impacts on the penguin colony from the dredging campaign is potentially considerable. Reduced prey availability could result in an increase in mortality of adults, as well as a decrease in breeding success and even the participation in breeding due to poorer body condition of the adults. As such, not only could the colony be impacted during the dredging campaign, but also for several years following dredging. This is because the successful chicks only return to their natal colony when they are 2-3 years old. Therefore, a reduction in chick production alone will impact the colony for several years, as will an immediate reduction in the adult breeding population from starvation.

4 Impact of dredging on fish and their habitats

Dredging can cause ecosystem and food web changes (Lukies et al. 2021). It can increase concentrations of suspended matter, decreases water transparency and increases sedimentation. Both increased turbidity and sedimentation can impact seagrasses, regarded as important habitat for fish (Wegner et al. 2018). The increased turbidity can reduce the light or alter the light quality available to seagrasses, causing sub-lethal and lethal effects, whilst increased sedimentation can directly smother seagrasses and other benthic habitats and negatively impact the benthic fauna, vital for the well-being of the seagrass beds. Dredging can also reduce the amount of dissolved oxygen and increase nutrient concentrations and the production of hydrogen sulphide (Erftemeijer and Lewis III 2006; McMahon et al. 2017), re-suspend contaminants and create noise (Wegner et al. 2017). Dredging impacts on fish include avoidance of an area, physical damage, behavioural impacts such as inability to locate appropriate habitat and reduced foraging ability, physiological impacts, reduced hatching success and mortality (Wegner et al. 2017, Wegner et al. 2018 and refs within). However, the vulnerability of fish to impacts from dredging is dependent on their life stage and the duration of their exposure (Wenger et al. 2018). Whilst larval and juvenile fish are more vulnerable to impacts from dredging, this will ultimately impact the regulation of fish populations (Wenger et al. 2018). Thus the impacts of dredging on fish, and thus penguins, could extend beyond the dredging campaign.

5 Possible strategies to prevent penguins from starving during the dredging campaign

The Environmental Protection Authority has recently published technical guidance for dredging proposals (Environmental Protection Authority 2021). These guidelines describe an impact prediction and assessment framework. Based on these guidelines, dredging impacts can be minimised when an array of information is incorporated into the design of the dredging project, including (but not limited to) 1) adequately detailed, up-to-date, fine-scale benthic habitat maps, 2) historical and contemporary data sets for a suite of dredging relevant environmental variables, 3) spatially and temporally appropriate hydrodynamic modelling, sediment transport modelling and ecological response modelling, 4) calibration and validation of the numerical models 5) dredge plume modelling which considers variability in physical forcings, sediment release rates, dredge operation and management scenarios, 6) biological effects criteria that include a frequency of occurrence and/or duration of occurrence, 7) consideration of critical windows of environmental sensitivity for the flora and fauna that utilise the area to be dredged, 8) the use of silt curtains where appropriate, 9) the use of dredges with sediment management devices, and 10) consideration of both the simultaneous effects of natural processes and dredging induced changes (Environmental Protection Authority 2021). However, site-specific knowledge gaps exist for many of these guidelines, many (hopefully) of which will be addressed within the WAMSI Westport Marine Science Program. In the absence of this site-specific knowledge, as well as a detailed dredging management plan, there are two major options available to prevent significant impacts on the penguin population from dredging, i.e. impeded foraging ability due to turbidity or impacts from noise:

1) reduce impacts of dredging on penguins and their fish prey and their important habitats:
    a. Avoid dredging during breeding and pre-moult periods (April-Jan).
    b. Employ best practice dredging management to control the extent, duration and intensity of the dredge plume on penguins and their important prey species and habitats.
2) aggregate fish in an area not impacted by dredging but within the typical home range of the penguins during the breeding season.

As the typical home range for the Little Penguins is within Cockburn Sound, then both options are designed to maintain a prey presence within Cockburn Sound.

5.1 Reduce Dredging Impacts on Penguin Fish Prey

To minimize the impacts of dredging on coastal fish, sediment concentrations should be kept below critical thresholds (e.g. 44mg/L for less than 24 hours (Wegner et al. 2018) and/or apply seasonal limits on dredging, based on known spawning and recruitment times (Wegner et al. 2018). This threshold of 44mg/L for less than 24 hours was predicted to protect 95% of the species used within the model. However, none of the species used in the model by Wegner et al. (2018) are penguin prey species. Furthermore, the threshold was based on data collected from global fisheries, and therefore need to be treated cautiously. As for spawning and recruitment times, there is limited information on the timing of spawning and recruitment for the major prey of penguins in Cockburn Sound, and even which habitats are important for them (Table 1) (although information from WAMSI Project 4.2.1 will help fill these knowledge gaps). Thus, it is currently not possible to identify effective seasonal limits for the dredging campaign. Data from species within Cockburn Sound is essential for the development of effective thresholds to minimise the impacts of sediment concentrations on the important prey species for Little Penguins. Thus, until thresholds and/or seasonal limits are available for each prey species (an expected outcome for at least **a limited number of species** in project 4.4), a more conservative approach for sediment concentration thresholds and/or seasonal limits is warranted.

Table 1. The timing of spawning and presence, and important habitats for major prey species of Little Penguins foraging in Cockburn Sound, Western Australia. Presence is for Larvae(L) and/or Juveniles (J). Timing refers to the event occurring within Cockburn Sound. Species in bold typically are more prevalent in the diets of Little Penguins from Garden Island (Cannell unpubl. data)

Fish Species	Spawning	Presence (Larvae/Juveniles)	Important habitat
Pilchard (*Sardinops sagax*)	Unlikely to occur in CS	Unknown (L and J)	Deeper water of CS, particularly central basin
Anchovy (*Engraulis australis*)	November	Present but timing unknown (J)	SE CS
Scaly mackerel (*Sardinella lemuru*)	N/A as not in CS	Unlikely (L) Unknown (J)	Shallow waters, East CS, Woodman Point to Mangles Bay. Smaller fish offshore around Bell Buoy, mostly in summer. Hard bottom, near drop-offs
Sandy sprat (*Hyperlophus vittatus*)	Unknown	Eggs found May-Nov, larvae less abundant	Unknown
Blue sprat (*Spratelloides robustus*)	Unknown	Unknown	Unknown
Hardyheads (*Atherinomorus vaigiensis*)	Unknown	Unknown	Unknown
Sea mullet (*Mugil cephalus*)	Unknown	Unknown	Unknown

5.2 Reduce Dredging Impacts on Penguin Fish Prey Habitat

It is not currently possible to determine strategies to limit impacts on important penguin prey habitats, as it is unclear which habitats are important for all the penguin prey species. However, such information will be collected, for potentially **some of the fish prey**, within project 4.2.1. Once this has been determined, it is more likely that strategies to minimise the impact of dredging on important penguin prey fish habitat can be developed. Whilst it is known that seagrass is generally important for many fish species, experiments on specific seagrass populations from northwest WA showed that seagrass recovery after periods of light reduction were rapid but that 10 days of continuous low light was more detrimental than 5 days of continuous low light (WAMSI 2019b). How this translates to the impacts of dredging on seagrass habitat in Cockburn Sound is unknown. However, strategies to minimise the impacts of dredging on seagrass within Cockburn Sound is a likely outcome of project 2.2 and should be incorporated in the strategies to minimise starvation of little penguins during the dredging campaign.

5.3 Aggregate penguin fish prey within the home range of little penguins

To aggregate fish prey within the home range of little penguins, one option would be to build a large fish pen that could be stocked with penguin fish prey. However, this would require commercial fish operators to collect fish prey such as pilchards, anchovy, scaly mackerel, sandy sprat and blue sprat with a size range of 40-100 mm long (Klomp and Wooller 1988, Wienecke 1989, Connard 1995, Bradley et al. 1997, Cannell unpubl. data), using probably purse seine nets. The fish would then need to be transported to the pen/s. Whilst this has been done for pilchards with minimal initial mortality (Fletcher 1995), the smaller size and/or different species necessary fir the penguins are more delicate and thus mortality would likely be high. For those that did survive, stress and potential injury would result in increased risk of disease, which could in turn increase the risk of disease to the wild stock. Additionally, the penned fish could die from restricted movement. It is unknown how many fish would be required daily to feed not only the GI penguins, but also the PI penguins that utilise Cockburn Sound. This is because the penguins breed and moult asynchronously, thus the resource requirement would vary constantly, e.g. a penguin feeding two chicks requires more food, and potentially different prey species (Cannell unpubl. data), compared to a penguin feeding itself, and compared to a penguin building up mass during the pre-moult period. Even if it was possible to stock enough fish on a regular basis, the penned fish may need to be fed, which could have ecosystem effects as well as labour costs. Give the small size range of the fish, a small mesh size would be required (unlike that used for fish farms for larger fish such as tuna and barramundi), and hence there would be increased force on the net from water movement as well as additional stress from biofouling. Thus, the fish pens would require initial robust engineering design research. Furthermore, sharks are known to constantly bite holes in the nets of the local commercial fishermen, so it is presumed that the sharks would be equally attracted to the fish pen. With the increased force on the net, and damage from other marine fauna, it is likely that consistent maintenance of the net would be necessary. Research would also be necessary to determine the effect of having multiple fish species present in an enclosed space simultaneously. Entanglement in the nets by penguins, dolphins and sea lions would need to be considered. Additionally, if penguins learnt to use the fish pen as a food resource, then this could result in increased predation by sea lions on the concentrated penguins within the fish pen. In the scenario where the penguins did utilise the pen, there would be increased competition between the penguins in a smaller space, which would ultimately result in increased energy expenditure and likely poorer breeding outcomes. Other seabirds would also likely be attracted to the fish pen, thus large numbers of predators would be vying for a limited resource. Finally, theft (Fletcher 1995) and vandalism would need to be considered. Thus, much expense and effort would be put into an option that has limited chance of success.

Many fish species are known to aggregate under floating structures such as algal mats, floats and fish aggregating devices (FADs) (Castro et al. 2002). FADs have been commonly used to aggregate pelagic fish for both commercial and recreational fishing activities (Castro et al. 2002; Floyd and Pauly 1984; Friedlander et al. 1994; Wilson et al. 2020). FADs can be deliberate attempts to aggregate fish, or a by-product of a device designed for another use (e.g. offshore buoys, (Relini et al. 2000). The design of FADs varies, e.g. floating devices made from natural materials such as cork slabs, sheets of plywood, (bamboo) rafts with attached anchor stones, palm fronds inserted into ropes (de Sylva 1982); floating devices made from steel, aluminium and fibreglass (Anderson and Gates 1996); and even lights directed from fishing boats or suspended from a boat during the evening (Dalzell and Lewis 1989). They can be suspended at the surface, just below the surface or in mid-water (de SYLVA 1982) and can be free floating or anchored (Castro et al. 2002). Their range of influence may extend to approximately 10 km from the FAD (Dagorn et al. 2000; Girard et al. 2004), but the residency time of fish at FADs seems to be low, at least for tuna (Girard et al. 2004). Whilst FADs have been used effectively globally to improve both commercial and recreational fishing success, the efficacy of the FADs was found to be inconsistent between sites in the US Virgin Islands (Friedlander et al. 1994). FADs deployed in the oceanic waters off Broken and Botany Bay, NSW, were found to attract the juveniles and larvae of several fish species, including some of the species consumed by the penguins in Cockburn Sound (Druce and Kingsford 1995). However, the dynamics of the fish using FADs can change with time, with respect to both fish stage and species. The success of FADs is dependent on a number of environmental variables including water clarity, water colour, water quality, current speed, proximity to reefs and other important fish habitat, the design of the FAD, rugosity of sea floor, depth of area and the length of time in the water (Anderson and Gates 1996; de Sylva 1982).

Aside from the various factors that affect the success of FADS, noted above, there are multiple considerations for the deployment and use of FADs to assist in the prevention of starvation of penguins during the dredging campaign. These include 1) the location of the FADs, e.g. they should not be placed in areas which already concentrate pelagic fishes, in shipping lanes or in areas where there is a likely of conflict of use between groups (Friedlander et al. 1994); 2) the management of FADs, such as location and enforcement of exclusion zones around the FAD, and its maintenance, if needed; 3) FAD design, e.g. a design which resulted in the entanglement of marine fauna would not be appropriate. Additionally, even though boats (and FADs) with lights have been shown to aggregate fish, and thus the foraging opportunity of some seabirds (Arcos and Oro 2002), it would be undesirable to use lights on the FADs for Little Penguins. Although Little Penguins are visual predators, requiring a specific amount of light to forage (Cannell and Cullen 1998), underwater illumination might entice them to feed in the evening, which could impact the penguins returning to feed chicks or swap with their partners for parental duties; and 4) the development and implementation of a scientifically rigorous monitoring program to determine the efficacy of the FADs, such as the response by fish and penguins to the FADs e.g. the attraction of FADs to larval and juvenile fish species may not improve the feeding efficiency of penguins if the size range attracted is less than that eaten by the penguins. Such a monitoring program would need the involvement of key research groups to determine the most appropriate methodology and financial requirements to monitor the efficacy of the FADs.

The deployment of FADs would require 1) input from the Department of Transport for advice regarding the location of the FADs and associated boating exclusion area as well as the enforcement of a boating exclusion area i.e. it would be undesirable to have boating around the FADs, which could result in mortality of an increased concentration of penguins and other marine fauna from collisions with boats; 2) input from the Department of Primary Industries and Regional Development for advice regarding the location and enforcement of a fishery exclusion area around the FADs; 3) a targeted educational/awareness program of the zones around the FADs and the likely benefits of the FADs to the penguins; and 4) detailed modelling of the likely turbidity in Cockburn Sound associated with the dredging to avoid placement of the FADs in areas with turbidity greater than the thresholds to reduce impacts on fish, to be advised by project 4.4 .

6 Conclusions

The potential direct and indirect impacts on Little Penguins of the dredging campaign during construction of a port in Cockburn Sound have been identified. These impacts are related to turbidity and noise elicited during the dredging. They include a reduction in their foraging ability as Little Penguins are visual predators, behavioural and physiological impacts from noise, a reduction in fish presence within the home range of the penguins and impacts on important fish habitat. To prevent penguins from potentially starving during the dredging campaign, the options include 1) no dredging during breeding or pre-moult, 2) reduce dredging impacts on penguin fish prey, 3) reduce dredging impacts on important fish habitat and 4) use Fish Aggregating Devices (FADs) to aggregate fish in areas not impacted by dredging but within the penguins' home range. Given the lack of current knowledge on the thresholds necessary to reduce impacts on penguin fish prey and important fish habitat, and hence the areas that would best be suited for the location of FADs, it is not known if these options must occur concurrently. However, outcomes of multiple projects within the WAMSI Westport Marine Science Program will hopefully be able to address this. Whilst these options have been discussed in relation to increased turbidity from dredging, it is paramount to also consider the noise impacts of construction related to pile-driving and dredging, both on the penguins and the fish they prey on.

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