APPENDIX H: UTAS ROCK LOBSTER TRANSFERABILITY OF KNOWLEDGE STUDY

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Transferability of knowledge between Southern Rock lobster (*Jasus edwardsii*) and Western rock lobster (*Panulirus cygnus*)

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1. Background

Pilot Energy is seeking approval to carry out the Eureka 3D Marine Seismic Survey in Commonwealth waters off the mid-west coast of Western Australia, where Western rock lobster (WRL; *Panulirus cygnus*) inhabit and concern has been raised over potential impacts to the WRL fishery by this seismic survey.

Consultation with WRL fisheries stakeholders in the region has indicated that they believe that the research on the effects of seismic signals on Southern Rock Lobsters (SRL; *Jasus edwardsii*) has limited relevance for understanding the potential impacts of seismic exposure on WRL, based on their experience that WRL are less robust and resilient than SRL. On the other hand, Pilot Energy believe that, despite some distinct differences in their biology, ecology, and distribution, the two species overall share a great deal of similarities in their taxonomy, habitat utilisation, size, appearance, life cycle, diet, and economic importance, which makes the research conducted on SRL relevant. To better understand the significance of these similarities and differences and to evaluate whether there are any indicators to suggest a difference in their resilience or sensitivity to seismic exposure, a review of the extant literature was conducted to compare the two species to identify similarities and differences to examine the potential transferability of knowledge between SRL and WRL.

Specific topics requested to be included in the report:

- Present a background on Southern Rock Lobster and Western Rock Lobster, including their taxonomy, distribution, and ecological characteristics. This is covered.
- Describe the current scientific understanding of both species, highlighting any significant differences or similarities between them in relation to the range of effects from seismic sound. This is covered.

- Briefly identify the impact of environmental factors on the biology and ecology of both species, including temperature, salinity, habitat availability, and food sources. This is covered.
- Identify key findings and research gaps regarding the biology, ecology, habitat preferences, behaviour, and life history of both species. This is covered.
- Identify any existing studies that have investigated the transferability of scientific knowledge between closely related lobster species. There are no existing studies.
- Assess the extent to which environmental conditions influence the transferability of scientific knowledge between Southern Rock Lobster and Western Rock Lobster in relation to seismic sound. This is covered.
- Assess the applicability and transferability of the scientific knowledge obtained from Southern Rock Lobster to Western Rock Lobster. This is covered.
- Identify any limitations or constraints associated with transferring scientific findings between the two species. This is covered.

2. Southern rock lobster (*Jasus edwardsii*)

Jasus edwardsii (Hutton, 1877), a crustacean of the order Decapoda, is a species of spiny lobster, which belongs to the Palinuridae family and genus *Jasus*.

Southern rock lobster (SRL) is a large benthic species inhabiting coastal reefs where they play an important ecological role in rocky reef ecosystems (Pinkerton et al. (2008) and are targeted by a socioeconomically important fishery across their distribution. They are omnivorous, feeding mostly at night. Ontogenetic changes in southern rock lobster feeding habits have been found, with juveniles feeding on ophiuroids, isopods and bivalves and adults on bivalves, crabs and other crustaceans, urchins, and gastropods (Edmunds, 1995)

Distribution and habitat:

SRL are native along the southern coast of Australia and around New Zealand (Figure 1)(Phillips and Kittaka, 2008). The Australian range extends from southern Western Australia to New South Wales, with the bulk of the population found in the southeastern states of South Australia, Victoria and Tasmania, where they occur to depths from 1 to around 200 m, experiencing water temperatures from 6 to 23 °C (McKoy, 1985).

Across their distribution, SRL generally inhabit rocky bryozoan or aeolianite limestone reefs but are also found on outcrops of igneous rocks such as granite (Phillips and Kittaka, 2008). Within coastal ecosystems, SRL are not evenly distributed but are often more abundant in complex habitats such as algal-dominated reef that provide daytime shelter and a variety of microhabitats for nocturnal foraging (MacDiarmid et al., 2013; Phillips et al., 2013).



Figure 1: Distribution of Southern rock lobster (SRL) in Australia (Linnane, 2020).

Life history:

Stock structure:

Previous studies based on mitochondrial DNA analysis, suggested that SRL encompass a single genetic stock, with little evidence of population sub-structuring across mainland Australia, Tasmania and New Zealand (Brasher et al., 1992; Ovenden et al., 1992). However, a more recent study found small levels of genetic differentiation across southern Tasmania, with significant levels of differentiation between Tasmania and New Zealand (Morgan et al., 2013). Furthermore, larval transport models via ocean currents suggest that population structure is likely to be complex (Stephen et al., 2003; Bruce et al., 2007).

Growth:

SRL individuals' carapaces can grow up to 230 mm in length and can exceed 8 kilogram in weight with a life span of over 20 years.

Water temperature and diet appear to be key factors affecting growth in SRL (Hooker et al., 1997; Radford et al., 2007). In the southwest of Tasmania, the population is characterized by slow growing, small individuals with relatively small size at onset of maturity, by contrast, in

the north and east of the state, growth is faster, individuals grow larger and they have a larger size of onset of maturity (Gardner and Van Putten, 2008; McLeay et al., 2019). Consequently, size at maturity in southern rock lobster is directly correlated with environmental temperature (McLeay et al., 2019).

Moulting is a complex process in which lobster shed their carapace to facilitate growth. SRL demonstrate sexual asynchrony in moult cycles, with males moulting between October and November and females late April to June. MacDiarmid (1989) also found that moulting occurred predominantly at night in shallow water and that the timing of moulting and the number of eggs produced was correlated to lobster size. It has been suggested that spatial differences in the time of moult in SRL might be due to variation in temperature and photoperiod, with latitudinal trends in reproduction and time of moult similar (Quackenbush and Herrnkind 1983, Nelson 1986, Lipcius and Herrnkind 1987).

Reproduction

Sexual maturity in female SRL is reached 3-7 years post-settlement at a size ranging from 60-120 mm carapace length, depending on locality (Phillips and Kittaka, 2008).

Mature SRL usually move into deeper offshore water to breed. Reproduction occurs between April and July, depending on location. Immediately following the moulting of females, males deposit a spermatophore on the sternal plates of females, then females extrude their egg mass and external fertilization occurs (Phillips and Booth, 1994). The females then brood the eggs for approximately 3-4 months over the winter season until hatching which usually peaks in September through October (MacDiarmid et al., 2013).

Life cycle

After hatching, SRL larvae (called phyllosoma) have a pelagic phase with a duration of at least 12 to 24 months (Chiswell and Booth, 2017). During this phase, the larva undergo 11 moult

cycles in the open ocean (Phillips and McWilliam, 1986), then the phyllosoma moult into the puerulus stage, in which they actively swim from the deeper ocean to a costal reef to settle into near-shore habitats (Phillips, 2008). It is not clear how SRL find the coast, with a range of possible mechanisms suggested including orientation towards nearshore sources of underwater sound, water chemistry, electromagnetic fields and hydrodynamic cues (Jeffs et al., 2005). The puerulus is a short-lived, transitional stage between planktonic phyllosoma and the bottom-living juvenile. Once the puerulus is settled, individuals moult into a pigmented juvenile (approx. 5 cm in carapace length) within two weeks (Pecl et al., 2009). A young immature lobster will moult about 25 times per year with the time between moults (known as moult increment) increasing with each moult.

During the juvenile phase, SRL are susceptible to high predation mortality due to their small size and extended planktonic duration, then when individuals reach large sizes ("size refuge") they tend to aggregate more with conspecifics (Buttler et al., 2016). SRL undertake predictable seasonal movements between depths, with adult males and females moving up and down the reef at different times of the year with these patterns seemingly related to the annual timing of moulting, reproduction and feeding activities (MacDiarmid1991).

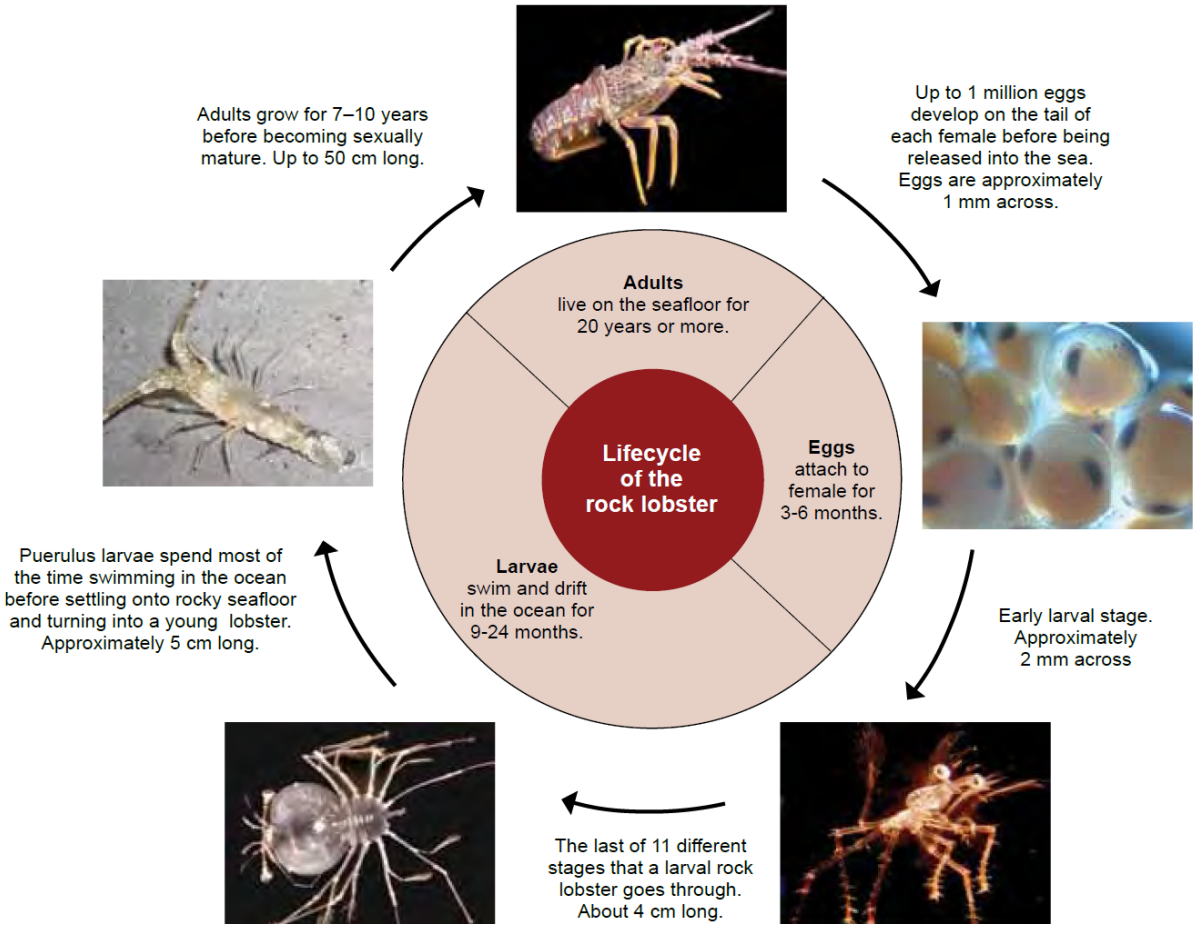


Figure 2: Life cycle of Southern rock lobster (Jasus edwardsii). Figure from (Pecl et al., 2009).

Anthropogenic impacts

Environmental condition

Warming water temperatures will affect SRL directly and indirectly into the future. Temperature has a controlling effect on the biology of ectothermic species, affecting their physiology and therefore behaviour. For example, temperature effects physiological processes such as aerobic scope, the amount of energy available to individual lobsters to perform non-essential body processes as well as survival, growth, feeding, metabolism, cardiac performance, reproduction and predator avoidance (Fitzgibbon et al., 2012; Fitzgibbon et al., 2014; Fitzgibbon et al., 2017b; Oellermann et al., 2020; Twiname et al., 2020). In SRL, high temperature has been associated with a decrease in growth due to a reduction in intermolt

period, i.e. more frequent moulting (Thomas et al., 2000). Temperature also affects the survival of SRL, with mortality increasing at temperatures above 24°C. Changes in temperature will affect these processes differently across the range of the SRL population, with climate change modelling of SRL in Tasmania indicating that current declines in recruitment will likely continue, with the rate of these declines dependent on the level of warming (Pecl et al., 2009). In the short term, declines in recruitment will be masked by increases in biomass of SRL due to warming effects on growth rates. However, in the long term, decreases in recruitment as well as effects of temperature on growth will result in a decline in the biomass of SRL in Tasmania. This will occur first, and be most pronounced, in the north of the state, where temperatures are already close to the thermal limits of SRL.

Kelp habitat provides food, and refuge for many species, including southern rock lobster, but coverage has reduced over the last few decades around Tasmania due to climate change. The presence or absence of kelp has been found to influence settlement and the overnight predation of early life stages, suggesting that kelp habitat promotes SRL recruitment and survival against predators (Hinojosa et al., 2014). Consequently, the decline in kelp habitat due to climate change may potentially affect lobster recruitment and productivity.

Seismic impacts

The impacts of seismic surveys and air gun signals in southern rock lobster has been investigated across several different life stages. In adults, exposure to a single air gun has shown impairment of immune function, nutritional condition (Fitzgibbon et al., 2017a), and dorsoventral righting reflex, as well as the persistent damage to the mechanosensory statocyst organ (Day et al., 2019). Egg-bearing (berried) female South rock lobster exposed to air gun signals did not show any impact in the number or quality of offspring, with hatched larval lobster not showing any impact from exposure early in the embryonic period (Day et al., 2016).

In juveniles and puerulus, no mortality was observed when exposed to a full commercial seismic array, however, air guns signals caused righting impairments to at least 500m from the source (Day et al., 2022), suggesting statocyst damage as found for the adults with a single airgun (Day et al., 2019). Day et al. (2022) also found that the intermoult duration significantly increased in juveniles exposed at 0 m from the seismic source, suggesting the potential for slowed development, growth, and physiological stress.

A statistical analysis of catch-per-unit-effort (CPUE) data collected over nearly 30 years in the Victorian southern rock lobster fishery showed no influence of historical seismic survey activity, through the authors noted a lack of sensitivity due to the preponderance of surveys conducted in deep water away from fishing areas and suggested that catch rates would have had to decrease by around 50% to detect an impact (Perry & Gason, 2006).

3. Western rock lobster (*Panulirus cygnus*)

The western rock lobster (WRL), *Panulirus cygnus* (George, 1962), is a decapod crustacean of the family Palinuridae (spiny lobster) and genus *Panulirus*.

They are opportunistic omnivores, with a diet composed of different variety of plants and animals, such as crabs, molluscs, small crustaceans, bivalves, coralline algae, or sponges (Joll and Phillips, 1984; Edgar, 1990; Jernakoff et al., 1993; MacArthur et al., 2008). In shallow inshore areas, WRL forage throughout the night in seagrass meadows surrounding reef, moving distances of up to 300 m (Jernakoff, 1987). Studies suggest that western rock lobster are primary carnivorous and act as a secondary consumers, changing their diet from omnivorous in shallow inshore areas to a primarily carnivorous diet when they migrate to deep waters (de Lestang et al., 2012).

Distribution and habitat:

The western rock lobster is a temperate species distributed along the Western Australia coast, ranging from Exmouth to Albany (Figure 2) (Phillips, 2008). The greatest abundance of WRL is found in the mid-west coast (Geraldton to Perth) region relative to the northern and southern extents of the distribution (Bellchambers et al., 2012). Across their distribution, WRL experience a large range of temperatures which vary between 16°C to 27° C due the contrasting oceanic conditions created by the Leeuwin and the Capes Currents (Bellchambers et al., 2012).

The habitat of WRL is dominated by shallow water limestone reef and adjacent seagrass beds with the majority of the population occurring from the coast out to 40 to 60km seaward on the continental shelf, with some utilization of unvegetated areas during migration (Newman et al., 2023).

The western rock lobster has a spatially segregated life-cycle, where juveniles (1-5 years) inhabit inshore reefs (< 40 m depth), while adults (> 80 mm carapace length) migrate towards deep-water offshore habitats (> 40 m depth) (Bellchambers et al., 2012).

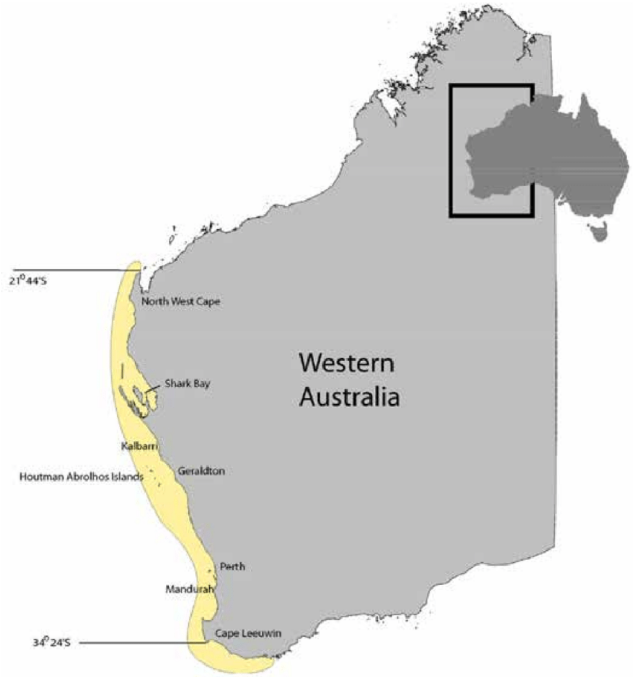


Figure 3: Distribution of the western rock lobster (Panulirus cygnus) along the Western Australian coastline (Bellchambers et al., 2012).

Life history:

Stock structure:

Previous analysis of molecular variance indicated no significant population structure along 960 km of coastline or genetic differentiation among temporal samples, suggesting that *P. cygnus* is a single, and panmictic population (Thompson et al., 1996; Kennington et al., 2013).

Growth:

Individuals can live for over 20 years and weigh up to 5.5 kg, though a 10 to 15 year lifespan, weight of less than 3 kg with a maximum carapace of 150 mm length is typical (Bellchambers et al., 2012; de Lestang et al., 2012; How et al., 2022).

The growth rate in WRL in both males and females is categorized by rapid juvenile growth, followed by a rate reduction after sexual maturity. de Lestang (2018) found that sex, temperature, population density and geographical position significantly impact growth rate in WRL. For example, growth had a significant negative correlation with increased population

density throughout the species distribution and a significant positive correlation with the warmer water temperatures experienced in the northern end of the distribution (de Lestang et al. 2009), attributed to increased moult frequency rather than larger moult increments (Chittleborough 1975).

In juveniles, growth rates do not differ between sexes (Chittleborough, 1976), however, in females a reduction in growth becomes increasingly more pronounced with sexual maturity, resulting in larger maximum sizes in males overall (Bellchambers et al., 2012), and often a relatively large size at first maturity (Melville-Smith and De Lestang, 2006).

Temperature is also directly correlated with the size and age of maturity, evident in the decreasing size of lobsters from south to north (Chittleborough, 1976; Chubb, 1991; Melville-Smith and De Lestang, 2006), as individuals become mature at about 5-7 years or 90 mm carapace length (CL) in the south whereas in warm northern waters, individuals mature at smaller sizes around 70 mm CL (Melville-Smith and De Lestang, 2006).

Reproduction:

Mature WRL individuals 6-7 years of age mate in late winter and early spring between August to September. First, males attach their spermatophores to the sternums of a receptive female. Then external fertilization takes place when the female releases eggs and scratches the spermatophoric mass to release motile sperm (Chittleborough, 1976). The eggs are thus fertilized as they are swept backwards from the female and become attached to the 'seatae' on the tail of the lobster, for a 5-to-8-week period depending on water temperature. The number of eggs produced by a particular female during a spawning period depends on the size of an individual lobster (Chubb, 1991), with large females capable of producing up to a million eggs and having a greater probability of spawning twice in a season (Morgan, 1972; Melville-Smith and De Lestang, 2006).

Life cycle:

WRL has a complex life cycle, including an oceanic larval phase followed by a longer benthic one (Figure 3). Individuals hatch as a 2 mm long planktonic phyllosoma larvae which drift offshore as far as 1500 km helped by winds and currents. At this stage, the larvae spend between nine to 11 months in a planktonic state growing through a series of moults (estimated 15 instars) until they reach approximately 35 mm long (Braine, 1979; Phillips et al., 1979). Phyllosoma then undergo one last moult, changing into a translucent puerulus (post-larvae) lobster at around 25 mm long (Figure 3, stage 6). The pueruli swim across the continental shelf toward the shore and settle in shallow reefs, which can occur thought the year with peaks from late-winter to mid-summer, with environmental factors driving this considerable variation (Caputi et al., 2010). The settled pueruli then go thought a series of moults, and individuals grow to become juvenile rock lobster.

Juvenile WRL concentrate mainly in shallow reefs where they spend between 4 to 5 years feeding and growing (Chittleborough, 1976). When they reach a size of 65 – 85 mm carapace length, individuals congregate and undergo a synchronized moult event over a three-to-four week period in late spring, changing colour from red to pale pink (Melville-Smith et al., 2003; Wade et al., 2008). Moulting is followed by a mass migration between late-November to mid-January each year to deeper water to reach spawning/breeding grounds which is generally referred to as a "white" migration (Bellchambers et al., 2012). Once there, white lobster gradually return to their normal red coloration and become sexually mature (Melville-Smith et al., 2003). Early juvenile spiny lobster trend to be solitary but as they grow they become gregarious (Phillips et al., 2013). In western rock lobster, Fitzpatrick et al. (1989) found that over 95% of newly settled pueruli and post-pueruli were solitary but less than 20% of lobsters were solitary after a year post-settlement.

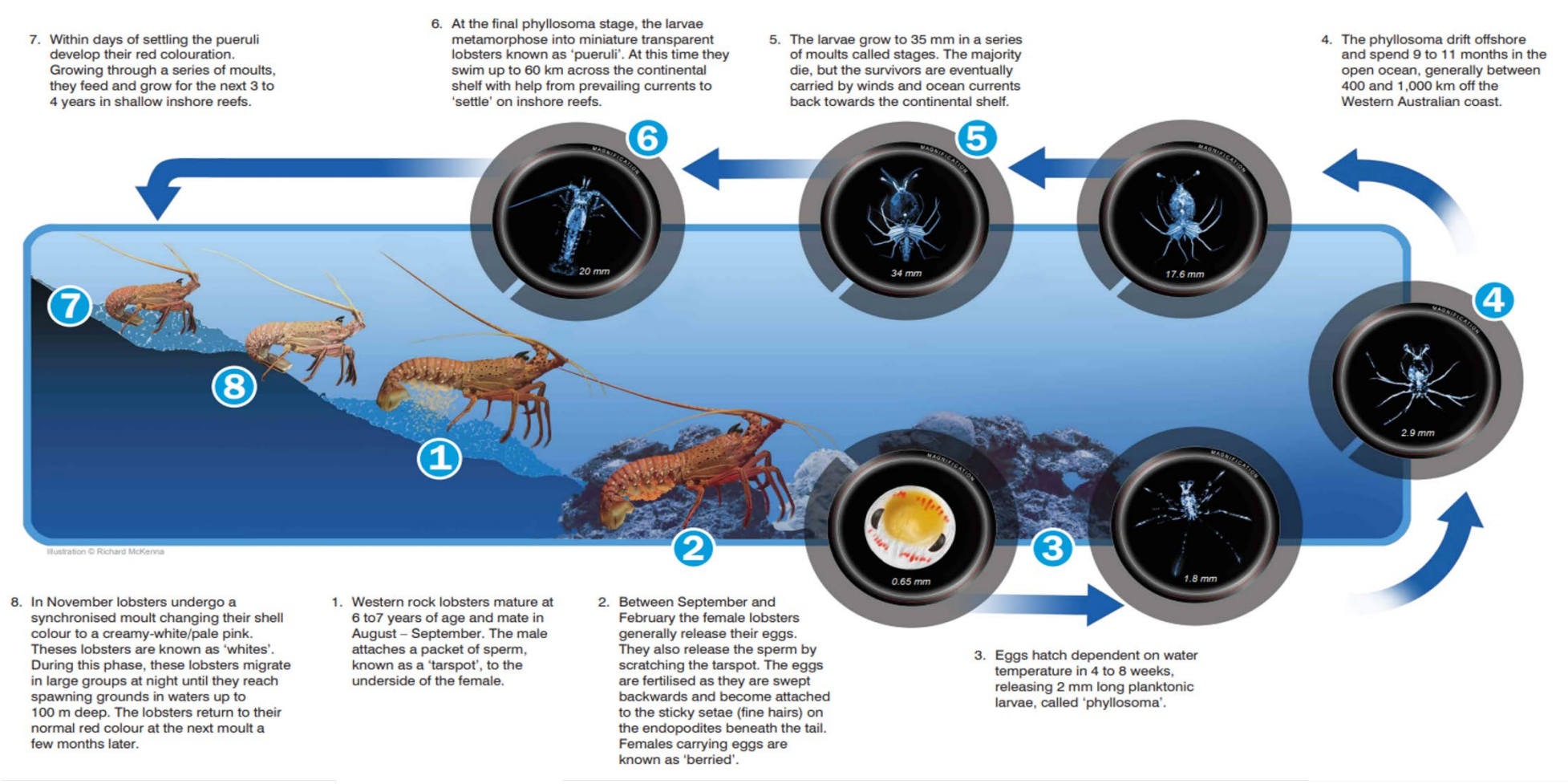


Figure 4: Life cycle of Panulirus cygnus (Western rock lobster). Diagram form the Western Australian Department of Primary Industries and Regional Development.

Anthropogenic impacts

Environmental conditions

Shifts in environmental conditions have been shown to influence different aspects of the WRL life history and stock populations (Caputi et al., 2010; Caputi et al., 2013). For instance, water temperature and storm activity are among the environmental parameters affecting puerulus settlement and timing, reducing the migration of white lobsters to northern breeding grounds, and decreasing the size at maturity within populations (Caputi et al., 1995; Caputi et al., 2001; Melville-Smith and De Lestang, 2006). Furthermore, significant changes in the size and age at sexual maturity of WRL over the past 35 years have been linked to climate change (Caputi et al., 2010).

Future changes are also predicted to affect the spatial distribution of western rock lobster as a result of the strength of the Leeuwin current which influences the large-scale migration of this species (de Lestang and Caputi, 2015). The Leeuwin Current, which brings warm, nutrient-poor waters southward along the edge of the West Australian continental shelf, is correlated with WRL puerulus settlement along the coast, with higher temperatures at the time of spawning correlated to below average WRL puerulus settlement (de Lestang et al., 2015). The timing of spawning is negatively correlated with temperature, and warmer temperatures may result in an earlier spawning which may cause a mismatch with other environmental factors such as peaks in ocean productivity and/or storms that assist the larvae returning to the coast and offshore water temperatures that help the early stage larval growth resulting in indirect impact to the larval settlement (de Lestang et al., 2015).

An extreme marine heat wave occurred along the Western Australia coast during 2011 and its impacts on marine ecosystems continue to linger, with the WRL population showing evidence of impact and incomplete recovery (Caputi et al., 2019). Survival and growth of the juveniles

may been impacted by the changes in the habitat and prey availability caused by the extreme event (Smale et al. (2017).

In previous studies under laboratory conditions, the effects of temperature had been examined in early stages of the WRL. Elevated temperatures resulted in reduced intermoult periods and post-moult sizes (Liddy et al., 2004) despite reports of faster growth (Johnston et al., 2008). Additionally, Johnston et al. (2008) also found that survival was higher at ambient temperature (around 19 °C) in stage 1 and 2 phyllosoma. There was an interaction effect of temperature and feeding frequency on post-pueruli where weight and carapace length were significantly higher at ambient temperatures (around 19 °C) when post-pueruli were fed three times a day, whereas at 23°C weight and carapace length were significantly greater when fed once per day (Johnston et al., 2008). Liddy et al. (2004) also measured the effects of food density, finding no significant effect on either the intermoult period or the size of the larvae.

Environmental variables were also linked to morbidity and mortality of western rock lobster during live transport, as holding time in export cartons, ambient temperature in the internal carton and chilling period before packing the lobster were found to have the greatest impact on survivability (Spanoghe and Bourne, 1998). Furthermore, previous studies have found that under stressful conditions, such as hot and windy conditions, when individuals are removed from the ocean or when encountering hypersaline conditions, WRL are particularly susceptible to leg loss due to their natural autonomy reflex (Davidson, 2004).

Seismic impacts

To date there has been only one study on the impact of seismic signals on WRL (de Lestang et al., 2024). In this study, tagged WRL collected from within the centre of the fishery were housed in cages and exposed to a shallow (~ 5m) commercial seismic survey before being released back into the fishery. The air gun array consisted of an 80 CUI inch sleeve gun array

(four 20-CUI guns) towed at 2 m depth, with an operating pressure of 2000 PSI and the maximum SPLpk – pk recorded from the four deployed hydrophones was 190, 216, 223, and 204 dB re 1 µPa.

Neither lobster mortality nor blood protein concentrations were affected immediately after exposure. Most lobsters examined retained all their legs; however, when focusing on lobsters with missing legs, a significant difference was found, with more legs missing in the exposure group. Additionally, lobsters exposed to air guns took significantly longer to right themselves, and their release behavior was slower compared to the control group.

In the first month following the seismic survey, exposed lobsters were less likely to be recaught in commercial lobster pots, with de Lestang et al. (2024) estimating an initial mortality of around 22% (0.06 – 0.68% CI) in this period. This differential recapture rate persisted over the subsequent two years, suggesting no further mortality beyond the first month after the survey.

4. Similarities and differences between SRL and WRL

SRL, *Jasus edwardsii* and WRL, *Panulirus cygnus* form the basis of two of the largest and most lucrative fisheries in Australia. Both species belong to the same spiny lobster family (Palinuridae) but not the same genus (i.e., *Jasus* vs. *Panulirus*). In Australia, SRL have a temperate distribution across the entirety of southern Australia, whereas WRL is endemic to Western Australia (Figure 5). Although also inhabiting temperate waters, WRL experience warmer water temperatures between 16 – 27°C, meanwhile SRL inhabit waters as cool as 6°C, reaching a maximum of 23°C (Figure 5). Both species usually seek shelter in cervices beneath rocks, corals or sponges, and under ledges or edges of vegetation.



Figure 5: Australian distribution of Southern rock lobster (red) and western rock lobster (blue).

In spiny lobsters (Palinuridae), there is a fivefold difference in size of the antennular plate, on which a sound producing apparatus, the plectrum, is located, such that the antennular plate reaches 38% of carapace length in some sound producers (Stridentes) compared to only 4% carapace length in non-sound producing spiny lobsters (Silentes) (Patek and Oakley, 2003). WRL are members of the Stridentes (Meyer-Rochow and Penrose, 1976; Patek and Oakley, 2003) and SRL the Silentes (Patek, 2002; Patek and Oakley, 2003). The Stridentes produce sound during interactions with predators, which most likely increases their chances of escape by causing the predator to pause momentarily (Meyer-Rochow and Penrose, 1976; Patek and Oakley, 2003; Staaterman et al., 2010). Antennae are spiny lobsters' primary weapons against predators and larger antennae are stronger and have the capacity to produce more force without structural failure (see review in Patek and Oakley, 2003), however, the Stridentes also have a secondary predator deterrent, i.e., sound.

Another key parameter in which the two lobsters vary is size, as WRL are usually smaller (maximum of 150 mm in carapace) than SRL which can reach 230 mm in carapace length. Furthermore, size at maturity are different between both species and within species due to spatial variation (Melville-Smith and De Lestang, 2006). In WRL in cooler waters individuals

become mature around 90 mm carapace length (CL), yet, in warm waters individuals mature at smaller sizes around 70 mm (Melville-Smith and De Lestang, 2006). In SRL in the warmer north of Tasmania, individuals grow at up to 20 mm per year and mature at 115 mm CL, whereas in the south they grow as slowly as 1 mm per year and mature at very small sizes of 60 mm CL (Gardner et al., 2006).

The early life history of both SRL and WRL follows the general trend of other palinurids, characterized by a long-lived, widely dispersed oceanic phyllosoma larval phase, followed by a briefer post larval puerulus transitional stage. Still, notable differences exist in the development of the two species, such as the time the phyllosoma larvae spend in the plankton, as *WRL* have a pelagic larval duration between 9 to 11 months, which is markedly shorter than that of SRL (12 to 24 months). The duration of the pueruli stage is also shorter in WRL, lasting about 2 weeks, in comparison to SRL, which may remain as pueruli for up to 70 days (Table 1).Regarding differences in their behaviour, WRL undertake large-scale mass migrations as juveniles (de Lestang, 2014), whereas SRL is restricted to more localised movement.

Table 1: Life history parameters for Jasus edwardsii and Panulirus cygnus.

	Jasus edwardsii (Southern rock lobster)	*Panulirus cygnus* (Western rock lobster)
Max. life span (year)	20	20 (usually 10 to 15)
Max. carapace	250	150
Max. Weight	8	< 3
Maturity (year)	3-7	6-7
Broods per year	1	1-2
Egg size index	300	400

Incubation period (months)	4-6	0.5-2
No. of instars	15-17	15
phyllosoma period (months)	12-24	9-11
Puerulus period (days)	70	15

While there is significantly less information available for WRL on the potential impacts of seismic signals compared to SRL, one similarity is that air guns signals cause righting impairments for both species (Day et al., 2019; Day et al., 2022; de Lestang et al., 2024) suggesting that like SRL (Day et al., 2019), airgun signals can damage the mechanosensory statocyst organ of WRL. The statocyst is a mechanoreceptive organ responsible for spatial orientation and equilibrium. In crustaceans, the basic structure of the statocyst is similar across species, consisting of a sac-like epidermal invagination of the cuticle (Finley and MacMillan, 2000). However, the location of the statocyst varies between groups; for example, in lobsters, it is in the basal segment of each antennule. To the best of our knowledge, the statocyst in WRL has not yet been examined. However, due to the similarities across different crustacean species, as well as the similarities between lobsters, it is likely that the WRL and SRL statocysts are similar. This suggests that the seismic impact observed on the SRL statocyst could be extrapolated to WRL. Reflex impairment and significant damage to the sensory hairs of the statocyst in SRL persist up to a year post-exposure to a single airgun (150 in^3) (Day et al., 2019), with the exposure calculated as equivalent to a 3065 in^3 commercial survey array passing at an estimated range of 100-500 meters.

Although ecological impacts of the chronic impairment of the righting reflex observed in exposed SRL and WRL have yet to be evaluated but the impairment suggests some impact on

the ability of an exposed lobster to function in the wild. Lobsters use input from the statocysts, leg proprioception receptors, and eyes in conjunction to identify and modulate their position (Neil, 1985), and removal of one of these inputs forces a greater reliance on the others (Schöne et al., 1983). Given the observed sensitivity of the SRL statocyst receptors to aquatic noise (Day et al., 2019), whether these other inputs are affected requires study, as they control a range of behaviours in lobsters, including the movement of the eyes, movement of the antennae, and coordination of the tail (Schöne et al., 1983; Neil, 1985; Newland and Neil, 1987). Indeed, removal of the statocyst entirely compromises the ability to modulate tail flip-mediated swimming to maintain correct body position (Newland and Neil, 1990) and to return to the substrate in an upright position (Newland and Neil, 1987) a posture necessary to initiate any further escape responses. de de Lestang et al. (2024) suggest that the impaired righting reflex in the WRL exposed to seismic signals in their study may have led to greater predation in these animals compared to the controls, thus explaining the suggested higher rate of mortality for exposed lobsters in the first month after the survey. The authors do note, however, that alternatively airgun exposure may have directly resulted in mortality that occurred after the lobsters were released but before they were first resampled (de Lestang et al., 2024).

In lobsters, overall, early benthic phase juveniles have high natural mortality levels and are the most vulnerable stages to predation, suffering high mortality from an array of fishes and motile invertebrates (e.g. crabs and octopus), despite mitigating adaptations including use of physical refuges, camouflage, cryptic behaviour, and nocturnality (Phillips, 2008). Estimates of WRL mortality occurring during the first year after settlement (from ages 1-2 years) were as high as 97-98%, with at least 80-84%, where only 0.9 to 6.4% survive from settlement until recruitment to the fishery at about 4.5 years of age (Phillips et al., 2003).These results clearly indicate that WRL experience very high natural mortality between the time of puerulus settlement in coastal reefs and when the lobsters move offshore and recruit into the fishery, with predation identified

as the primary cause of this natural mortality (Miller et al., 2023). To the best of our knowledge, no natural mortality rates have been published for SRL, however, P. Breen (National Institute of Water and Atmospheric Research, pers. Comm, in Phillips et al., 2003) indicates that conservative estimates of mortality rates are 75 % for the first year after settlement, 25% for 2 and 3 year and 10 % for subsequent years. In both species of lobster, natural mortality rates are higher during the first year after settlement and decrease as the lobsters age. These elevated early mortality rates could be more impactful if external stressors directly affect these early stages, potentially having a detrimental effect on population recruitment.

Fishing induce mortality has not been studied in WRL or SRL, however, mortality within pots due to predatory behaviour has been estimate for SRL. (Briceño et al., 2016) demonstrated that lobster mortality by predation in pots varies considerably across stock assessment areas and can follow seasonal cycles of fishing effort and lobster abundance. For example, in Tasmania, SRL mortality by octopus is estimated to represent an average of 2.35% of the total lobster harvest per year (Briceño et al., 2016), while in South Australia the mortality rate associated with octopus predation is 4% (Brock and Ward, 2004).

de Lestang et al. (2024) estimated that exposure to seismic surveys might cause up to 22% mortality in WRL, based on the lower number of recaptures observed in their study. As the survey was conducted in juvenile and shallow habitat, they suggested that a detectable and significant deleterious impact on WRL occurred, but only on lobster in approximately four year-classes. Yet, on a wider stock level, they suggested that the increase in mortality would be undetectable. However, if the survey was to be conducted in a deeper water area of the fishery, dominated by mature breeding individuals, any increased levels of mortality have the potential to reduce subsequent reproductive success, potentially having much broader implications.

Transferability of knowledge between lobster species:

While there have been published compilations about the biology of different groups of lobster (Phillips et al., 1992; Phillips and Booth, 1994; Phillips, 2008; Phillips et al., 2013; Wahle et al., 2021), no studies have previously investigated the potential transferability of scientific knowledge between related lobster species.

A recent review conducted by Peinado et al. (2021) on the potential transferability of knowledge between the effect of seismic surveys on crustaceans in general to Giant Crab (*Pseudocarcinus gigas*) specifically, suggested that if significant biological differences exist between species, extrapolation of the results might not be reliable, potentially even underestimating the potential severity of any impact. SRL and WRL differ in key biological parameters directly affecting survival and population dynamics (e.g., settlement time, duration of larval stages, growth). As such, the ability to draw specific conclusions around the potential risk of seismic surveys to WRL without sufficient species-specific information and predominately using SRL data is difficult and should be avoided where possible.

In the case of SRL and WRL, to the best of our knowledge only one study (Crear, 1998) has examined both species, in which a physiological investigation into methods of improving the post-capture survival of both species was undertaken. Crear (1998) shows clear differences between both species, with standard oxygen consumption, aerobic scope, and oxygen consumption at night almost twice as high in western rock lobster than in southern rock lobster. Ammonia excretion of WRL was generally also twice as high as that of SRL (Crear, 1998). Crear (1998) suggested that the differences between the species probably indicate that WRL have a higher capacity for activity than SRL. (Crear, 1998). Importantly, Crear (1998) did not

discuss the potential use of one species as a model of the other, rather, only observed differences between the species.

Given that air guns signals cause righting impairments for both SRL (Day et al., 2019; Day et al., 2022) and WRL (de Lestang et al., 2024) (de Lestang et al., unpublished), it is possible that there can be transferability of knowledge around potential impacts of seismic surveys between the species, but more research is needed to confirm this, given only one study has been undertaken for WRL. Given the current paucity of impact of seismic survey research for WRL, it is difficult to determine the extent to which environmental conditions may influence the transferability of scientific knowledge between SRL and WRL in relation to seismic sound. However, the fact that WRL inhabit seagrass meadows (Newman et al., 2023), along with limestone reef, whereas SRL are restricted to rocky reefs (limestone) and outcrops (igneous rocks such as granite) (Phillips and Kittaka, 2008), may influence how WRL are impacted by seismic signals, as these signals will attenuate more effectively through sediment (seagrass meadows) compared to rock. Note, however, that similar impacts were seen for SRL exposed on both limestone reef (Day et al., 2019) and sediment (Day et al., 2022), but the seismic sources and water depths were different between the studies. As such, direct comparison between potential impacts of seismic surveys across different habitats used by WRL may be worthwhile.

5. Discussion

Spiny lobster, including SRL and WRL, represent some of the most iconic and valuable species around the world, which have been subject to intensive fishing worldwide as they are generally shallow water species. Although grouped in a common category, there are substantial differences between the spiny lobster species, including aspects of growth, breeding, recruitment (Jeffs et al., 2013; Phillips et al., 2013), and noise production (Patek and Oakley,

2003), with further spatial variation due to differences in major ocean currents, temperature, depth and habitats (Plagányi et al., 2018).

The early stages of a lobster's life are essential for its development and survival, playing a key role in determining the overall population dynamics and resilience of lobster populations. A major difference between the life cycle of SRL and WRL is the length of the phyllosoma larval stage, which is much longer in SRL (12-24 months vs. 9-11 months). As a result, an impact to SRL at the phyllosoma stage might have a larger effect at the population level compared to WRL.

SRL and WRL have a distinctly different thermal niche. The variation in temperatures along the distribution in both species is a key factor to consider as ectotherms are highly dependent on external temperature for internal regulation. Thus, critical biological parameters have been identified to differ not only between SRL and WRL but also within each species across their geographical ranges, such as growth rates or size at maturity which are key population parameters (Phillips et al., 2013; McLeay et al., 2019). WRL are smaller in size and mature at a smaller size compared to SRL, so if there was an impact to subadult sizes, it might be more harmful to a SRL population than to that of a WRL population.

In lobster species, increases in water temperatures can accelerate growth and development, yet the nature of the relationship between fluctuation in temperature and size at maturity is not consistent among species (Chittleborough, 1975; Johnston et al., 2008; McMahan et al., 2016), with WRL and SRL showing opposite trends. In WRL, size at maturity is inversely correlated to temperature conditions experienced during growth (Melville-Smith and De Lestang, 2006), meanwhile in SRL, size at maturity is positively correlated with temperature (Linnane et al., 2008) (Hobday and Ryan, 1997; Gardner et al., 2006). Such divergent responses between species are thought to reflect species-specific adaptations in physiology that mediate the way

that temperature influences different essential processes such somatic growth or reproductive development.

Crustaceans in general are sensitive to changes in their local thermal environment, yet the impact of ocean warming on population traits are not yet well documented (McLeay et al., 2019). In Australia, both SRL and WRL are influenced by long term increases in water temperature which are projected to continue, resulting in variation of size at maturity or migrations patterns, which highlight the vulnerability of lobster stocks to climate change due to their long larval phase (Caputi et al., 2010; Caputi et al., 2013). Consequently, environmental factors are important drivers of fisheries recruitment variation, and they have become increasingly important under changing environmental conditions. Previous studies found direct effects on WRL and SRL under warming temperatures, such as reduced intermoult period (Thomas et al., 2000; Liddy et al., 2004) or survival (Thomas et al., 2000; Johnston et al., 2008). Furthermore, for both species an indirect impact on the population resulted from a change in habitat, e.g., decrease in kelp or algal coverage) (Hinojosa et al., 2014; Smale et al., 2017).

In regard to potential impacts of seismic surveys on crustaceans in general, previous studies have examined the effect of anthropogenic noises on sensory systems (Day et al., 2019), moulting (Day et al., 2022), behavioural responses (Cote et al., 2020), nutrition (Fitzgibbon et al., 2017a), immune function ((Fitzgibbon et al., 2017a) and physiological responses (Wale et al., 2013; Aimon et al., 2021), with research to date showing inconsistent results between species, parameters, and life history stages (Peinado et al., 2021; Solé et al., 2023). With major discrepancies/contradictions in the current literature across crustacean species, along with limited standardisation of sound source types or levels and inconsistent measuring and reporting of sound pressure, particle-motion, and ground vibration levels from these studies, it is extremely difficult to make any clear determination on what the impact of a seismic survey

on any species and its population may be. As such, until we have a better general understanding, species and life stages should be assessed individually where feasible.

6. References

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