NDRI Project 1.3:

Report: Evaluating nonindigenous marine species (NIMS) risks associated with decommissioning oil and gas infrastructure

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Executive Summary

The global placement of oil and gas infrastructure, including platforms, well heads and pipelines, represent significant hard substrate habitat with unique structural diversity. As this infrastructure reaches the end of operational life, companies and governments are facing decisions about which decommissioning option is most desirable based on a number of considerations, including the presence of NonIndigenous Marine Species (NIMS).

This report considers the relative impact of various decommissioning scenarios on changing the NIMS risk of transfer, survival and spread. NIMS are species that have been transferred, through human agency, to regions where they did not evolve. It should be noted that a subset of NIMS are deemed "invasive species" that have specific characteristics (such as rapid growth, short generation times, high dispersal) that increase the population size and geographic extent, and often aligned to environmental, economic, cultural or social impacts. A further subset of invasive species that have demonstrable impacts are deemed "invasive pests" or "pests" under regulation.

This examination identified 1,344 unique taxa associated with benthic habitat on or near global O&G infrastructure (including fish). 897 taxa were identified to species level, of which 179 had a recognised history of introduction (not necessarily in the reported study location).

One hundred of the 179 species are introduced or cryptogenic (of unknown origin) in Australian waters and provide a suite to consider the relative risks of decommissioning scenarios. At least 18 of the 179 species are identified as invasive pests, though several others have recognised impacts, with seven (7) identified as pests in Australian waters.

Two ecological traits, depth distribution and time larvae spend in the water column, were examined to determine relative changes in risks of transfer or survival of species between decommissioning scenarios. The majority of all binomial species (including native and NIMS) are restricted to waters less than 100 m deep whereas the majority of invasive species present in Australian waters were restricted to waters less than 50 m deep.

The time larvae spend in the water column, or Pelagic Larval Duration (PLD), provides an estimate of passive dispersal when combined with local current information where high PLDs would infer a larger dispersal distance and therefore increased connectivity. While PLD information was not available for a large number of species associated with O&G infrastructure, 49.6% of species with an invasion history and 45.4% of recognised invasive species have PLDs less than 21 days overall.

Examination of the decommissioning scenarios suggest that "leaving infrastructure in place" creates the least change in risk of NIMS transfer, survival or spread. The potential for natural (not human-mediated spread) would likely be unchanged once operational activity ceased.

In contrast, if infrastructure is in sufficiently deep water beyond the maximum depth limits of many NIMS or invasive species (>100 m), then removal of any structural elements in waters <50 m depth and placing infrastructure in waters >100 m (e.g., topple in place) would present the greatest reduction in NIMS or invasive species risk as it does not increase the footprint from baseline, and it minimizes survival of existing species due to depth limitations. It is worth noting that trade-offs between NIMS or invasive species reduction and fisheries benefits are outside the scope of this evaluation but should be considered in decision-making.

The decommissioning action of cutting O&G infrastructure could potentially trigger a spawning event and release biofouling material as tychoplankton (in the water column) or to the seabed. The depth of the "cut" of the O&G structure would influence the residual risk of survival: a cut >25 m but <50 m would potentially leave intact NIMS or invasive species populations, however defouling of this material could provide significant benefits. A "cut" of the O&G structure >50 m would substantially reduce the risk of leaving intact NIMS or invasive species populations.

All scenarios that involve relocating structures either by towing or on-board a vessel, increase the likelihood of NIMS and invasive species spread to new locations.

Glossary of Terms

Term	Definition
Binomial species	Taxa identified to both Genus and species. Binomial = two names.
Cryptogenic	= hidden origin. Species that the native origin cannot be determined.
Defouling	The removal of the benthic (fouling) community from anthropogenic substrates.
Droop	The pendulous growth of some colonial benthic organisms where a mass hangs down from the attached material and can break and descend to the seabed. Examples include colonial ascidians (e.g., *Didemnum vexillum*) and mussels (e.g., *Perna veridis*).
Invasive pest	A subset of invasive species that have demonstrable impacts deemed “invasive pests” or “pests” under regulation.
Invasive species	NonIndigenous species that have specific characteristics (such as rapid growth, short generation times, high dispersal) that increase the population size and geographic extent, and often align to environmental, economic, cultural or social impacts.
Lowest Taxonomic Unit (LTU)	An operational classification of taxa to the lowest determinable level (often not at the species level).
Nonbinomial species	Taxa that have not been identified to species level. This could include taxa that remain unidentified, or identified to any level of classification above species (e.g., Phylum, Class, Family or Genus).
NonIndigenous Marine Species (NIMS)	Marine and estuarine species that have been transferred, through human agency, to regions where they did not evolve.
Pest	A designation under regulation to identify taxa (most often species) that that have demonstrable impacts deemed to be unacceptable by the regulatory authority.
PLD	Pelagic Larval Duration – the length of time a reproductive propagule spends in the water column prior to settlement on hard substrates.
Taxon (pl. Taxa)	A uniquely identifiable organism.
Tychoplankton	= accidental plankton. Benthic species or pieces of species accidentally swept into the plankton that remain suspended due to neutral buoyancy.

Introduction

The global presence of offshore infrastructure associated with oil and gas (O&G) production includes over 12,000 platforms and well heads, and >180,000 km of pipelines, ranging from shallow nearshore habitats to waters greater than 300 m (Kaiser 2018, Jouffray et al. 2020; McLean et al. 2022). These are structurally diverse representing substantive subsurface hard benthic habitat in soft sediment dominated communities as well as shallow hard substrate in offshore pelagic ecosystems. Offshore infrastructure creates new environments through the operational addition of nutrients, provision of unique habitat and formation of reef like communities supporting higher diversity and attracting higher trophic levels (van Elden et al. 2019, 2022).

As these structures age and approach the end of operational life, several decommissioning options are under consideration (Macreadie et al. 2011, Fowler et al. 2018, Fowler et al. 2020, Schlappy et al. 2021) leading to the development of significant research initiatives to examine relevant options and considerations (e.g., Scientific and Environmental ROV Partnership using Existing industrial Technology - SERPENT; Influence of man-made Structures in The Ecosystem – INSITE North Sea; National Decommissioning Research Initiative – NDRI Australia). Proposed decommissioning options include leaving structures intact and in place; toppling the structure in place; disposing of the structure elsewhere at sea after removal, either by towing or heavy lift; disposing of the structure onshore after removal, either by towing or heavy lift; or dismantling and recycling (APPEA Decommissioning Guidelines).

While many benefits have been identified for leaving structures in place, one consistent concern has been the role these structures play in facilitating the establishment and spread of nonindigenous marine species (NIMS) (Sammarco et al. 2014, Page et al. 2019; Schlappy et al. 2021; McLean et al. 2022). Hazards in a marine biosecurity context are NIMS that are likely to arrive (or already be present) and that have the potential to cause adverse effects (harm). NIMS impacts include direct and indirect effects to environmental, economic, social and cultural values including population reductions, loss of genetic diversity, loss of biodiversity, shifts in trophic structure, alteration of nutrient cycles, affect commercial fisheries, clog seawater intakes and cooling pipes, increase drag on vessels and structures, impact human health through parasitic and pathogenic species, negatively affect amenity and recreational values (see Ojaveer et al. 2015).

The current recognition of NIMS associated with O&G infrastructure is poor; however, the association between NIMS and anthropogenic infrastructure has been well documented (e.g., Chapman and Carlton 1991; Glasby et al 2007).

A recent review by Schlappy et al. (2021) found that only four of the 44 papers (9.1%) they identified were focused on “non-native or invasive marine species” suggesting a paucity of information to support these concerns. Similarly, McLean et al. (2022) identified 16 priority science questions to address knowledge gaps in the ecological connectivity contributions of O&G structures which included the “role in the spread of invasives”. Three papers, Foster and Willan (1979), Wanless et al. (2006) and Pajuelo et al. (2016) highlight the arrival of NIMS in benthic communities of O&G structures sampled immediately after arrival from overseas. The platform jacket examined by Foster and Willan (1979) was constructed in Osaka, Japan and towed to central New Zealand over a 68 day journey in 1975. All species identified in their study were likely NIMS with origins from Japan, or anywhere along the journey (including the two-day bunkering in Rabaul), given that sampling occurred two days after arrival in New Zealand waters. In contrast, Wanless et al. (2006) reported on examination of a decommissioned semi-submersible platform that was lost at sea, while being towed from Brazil to Singapore, and stranded on Tristan de Cunha in 2006. They undertook an inventory of the platform six months after discovery of its stranding in April 2006. Pajuelo et al. (2016) examined two in transit semisubmersible platforms on Gran Canaria within hours of being docked in 2014 and 2015. They examined the benthic fish community and found 11 NIMS (oil rig 1 n=8; oil rig 2 n=7) and no species present on the rigs native to Gran Canaria. Additionally, Sammarco et al. (2014) and Page et al. (2019) identified NIMS on O&G structures in the Northern Gulf of Mexico and Southern California Bight, respectively.

Given the low number of recognized papers on NIMS associated with O&G structures, this study undertook a global analysis of species associated with O&G structures to facilitate the identification of NIMS likely to be present, noting that many studies focus on a biodiversity assessment and do not report or may not consider the native or introduced status of detected species. This information informs the differential effects of various decommissioning scenarios based on decommissioning actions and NIMS life history traits (e.g., depth distributions and larval duration in the water column).

Purpose and Objective

This project addresses the NDRI research priority 1

- To understand the potential impact of decommissioning O&G structures in life in the marine environment
    - item 3: Improved understanding of the risk and spread of invasive marine species (IMS) as a result of various decommissioning options and whether this is likely to be a matter of concern.

We propose to meet the required stated objective to identify evidence of IMS associated with existing O&G structures, and determine how IMS risk varies with different decommissioning scenarios and management regimes (for example, brought onboard a vessel and cleaned then brought to shore versus cleaning onshore; or, cleaned then reefed versus not cleaned and wet-towed then reefed).

Methods:

A global assessment of species associated with existing O&G structures with particular focus on species that have a recognised invasion history or have been identified as NIMS in examinations of benthic and associated communities on O&G structures was done by:

- identifying marine species reported from O&G structures, where possible identified according to ecoregions;
- determining which species are known to have a history of invasions or are known NIMS through comparison with global marine invader datasets (e.g., Hewitt et al. 2011; Bailey et al. 2020; World Register of Introduced Marine Species WRIMS); and
- determining which recognised NIMS overlap with existing distributions in Australia (Australian National Port Surveys; Hewitt 2002; Hewitt et al. 2009);

resulting in a list of recognised NIMS (or potential NIMS) associated with O&G structures.

Systematic literature review

A systematic literature review following the RepOrting standards for Systematic Evidence Syntheses (ROSES) protocol (Haddaway et al. 2017) was done. We searched the primary (peer reviewed scientific) literature between 1960 and June 2021 using the Scopus database to identify benthic marine species growing on offshore O&G structures. We used pairwise combinations of two sets of keywords: “benthic,” “biosecurity,” “biota,” “fouling,” “invasion” AND “oil and gas,” “offshore platform," "offshore structure" (e.g., "benthic" AND "oil and gas", "benthic" AND "offshore platform") to search for incidence in titles, abstracts and keywords. The resulting records for each pairwise combination were collated resulting in 1295 articles. Schlappy et al. (2021) provided 44 peer reviewed articles focused on biodiversity studies. Duplicate records were removed resulting in 1214 unique articles.

Articles were initially screened for author attribution and publication in English resulting in 1136 articles for further examination.

Titles, abstracts and keywords were examined to determine relevance based on whether the article reported benthic species, habitats or communities (174 articles), growing on (rather than near) or associated with an O&G platform or structure (rather than natural reef, shipwreck, offshore wind platform, etc) resulting in 99 articles for download and critical assessment of the complete text (Figure 1). Forty-nine articles were not readily or freely available (conference papers, book chapters, not available through the author); the remaining 50 articles were examined in full to determine if benthic marine species were reported with sufficient information to determine species name(s), sample location(s), and sample depth(s). Forty-four articles provided sufficient data for further analysis. We examined the references in the six discarded articles to identify additional references or datasets resulting in detection of nine additional articles, resulting in 53 datasets for further analysis.

Species lists collated from the 53 articles were checked against the World Register of Marine Species (WoRMS; https://www.marinespecies.org/) to update nomenclature and provide accurate phylogeny. These taxa represent a recognised pool of benthic species associated with offshore O&G structures.

Species with a history of invasions or recognized as NIMS

Taxa identified to binomial species on the emended species lists were then compared with global NIMS datasets (Hewitt et al. 2011; Bailey et al. 2020; WRIMS) to identify which species have an invasion history without regard to whether they were identified as NIMS at the sample location. The lists were compared against the known distribution of NIMS in Australia (Hewitt 2002; Hewitt et al. 2011; Bailey et al. 2020), or in datasets that record distributions drawing on datasets from Australian museum collections such as OBIS (https://obis.org/), FishBase (https://fishbase.mnhn.fr/) and SeaLifeBase (https://www.sealifebase.ca/).

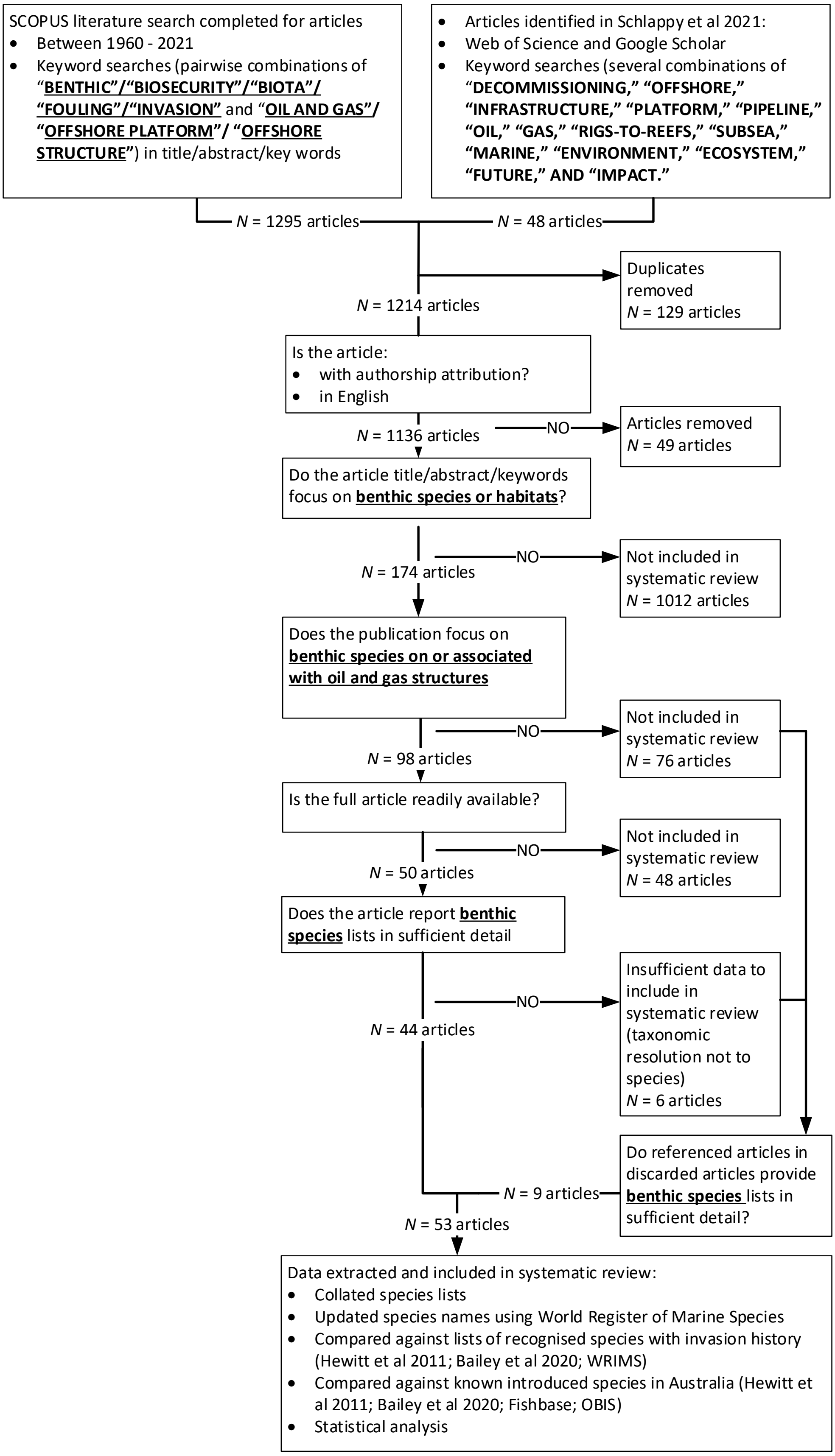

Figure 1: Flow diagram for Systematic Evidence Synthesis following the ROSES protocol (Haddaway et al. 2017).

Invasive marine species (i.e., species that have been designated as causing sufficient harm to environmental, economic, social or cultural values to be of concern) and marine species designated as “pests”, “weeds” or “Unwanted” organisms were collated from published lists for various jurisdictions including national (Australia, Canada, European Union, South Africa, USA, UK – Table S1) and state (Victoria, Western Australia) governments (Table S2).

Life history traits

Life history traits (depth distributions and duration of larval stage) were collated for all binomial species (classified to species) associated with O&G structures. Depth distributions for species were collated from WoRMS, OBIS, FishBase and SeaLifeBase. The minimum, average and maximum depth distributions were recorded for individual species based on records from the identified databases, regardless of global location.

The time that benthic species’ larvae spend in the water column, also known as Pelagic Larval Duration (PLD), is indicative of the distance a species may passively disperse on currents. PLDs were derived from the primary literature.

A systematic literature review following the Reporting standards for Systematic Evidence Syntheses (ROSES) protocol (Haddaway et al. 2017) was done. We searched the primary literature between 1960 and June 2021 using the Scopus database to identify pelagic larval durations of benthic marine species. We used combinations of two sets of keywords: “propagule” OR “larv*” OR “pelagic larv*” OR “planktonic” AND “duration” OR “PLD” to search for incidence in titles, abstracts and keywords. The resulting records for each pairwise combination were collated resulting in 332 unique articles.

Titles, abstracts and keywords were examined to determine relevance based on whether the article reported on PLD resulting in 158 articles for download and critical assessment of the complete text. All articles were available and were examined in full to determine if PLDs were reported with species lists. Species lists were collated where sufficient information to determine species name(s), sample location(s), and PLDs resulting in 3341 records. Collated species lists were checked against the World Register of Marine Species (WoRMS; https://www.marinespecies.org/) to update nomenclature and provide accurate phylogeny, resulting in 2893 unique binomial taxa.

These taxa were then compared against the recognised pool of benthic species associated with offshore O&G structures, resulting in PLDs recorded for 897 binomials.

Evaluation of decommissioning scenarios

Several decommissioning scenarios were considered to determine the relative risk of NIMS transfer and/or spread to natural reef. These included: leaving structures intact and in place; toppling the structure in place; disposing of the structure elsewhere at sea after removal, either by towing or heavy lift; disposing of the structure onshore after removal, either by towing or heavy lift; or dismantling and recycling (APPEA Decommissioning Guidelines).

The “leaving structures intact and in place” scenario was considered the baseline given that any NIMS that would have been introduced during the operational life of the O&G structure and the potential for natural (not human mediated spread) would likely be unchanged once operational activity ceased.

The other decommissioning scenarios therefore entail a variety of decommissioning actions which may alter the original state including intentional defouling, cutting or dismantling, placing on the seafloor at depth, towing to a new location or onshore, lifting out of the water onto a vessel and transferring to a new location or onshore. These decommissioning actions were compared to identify whether they were likely to increase the likelihood of NIMS transfer, survival, and/or spread to new locations *greater than the baseline scenario*.

Results

Systematic literature review

In total, the literature search yielded 53 articles with sufficient data to identify benthic species growing on, or associated with, benthic habitats of O&G offshore structures (Table 1) with locations based on the Marine Ecoregions of the World (MEOW) (Spalding et al. 2007). Those 53 articles predominantly come from temperate ecoregions (71.7%) in the Northern Hemisphere (MEOW Provinces: 67.9%: Temperate North Atlantic 45.2%; Temperate North Pacific 22.6%). Only two papers (3.7%) were identified from the temperate Southern Hemisphere (MEOW Province: Temperate Australasia - New Zealand and Temperate South America). Fifteen papers were identified from tropical regions (MEOW Provinces: 28.3%: Central Indo-Pacific 20.8%; Western Indo-Pacific 3.8%; Tropical Atlantic 3.8%) including seven papers from northern Australia (Figure 2).

The majority of papers were reports of benthic communities on O&G platforms (41; 77.4%), six papers (11.3%) were examination of pipelines, and the remainder of papers were examinations of semisubmersible platforms (3), well heads (2) and a jack up rig (1).

Several papers reported only on the fish community (5), or only identified fish to species level (1) (Table 1). Most of those papers examined ROV video footage that had insufficient resolution to identify most benthic taxa to species. Additionally, six papers explicitly focused on nonindigenous marine species (NIMS), often as single invertebrate species examinations (Table 1).

Species with a history of invasions or recognized as NIMS

Fourteen ecoregions had studies that reported at least one NIMS present on O&G structures (Figure 2).

A total of 16,210 records of benthic marine species (including demersal fish associated with structures) were collated from the 53 datasets. This resulted in 1,344 unique taxa: 897 taxa identified to species (binomials), with the remainder as non-binomials often at higher taxonomic levels (Genus or Family) and potentially representing multiple species. Taxa from 14 Phyla were identified, with key groups including Chordates (Fishes: 332; Ascidiacea - 16), Molluscs (152), Arthropods (144), Cnidaria (81) and Polychaete Annelids (68) (Figure 3).

Of the 897 taxa identified to species, 179 (20.0%) species across 11 Phyla had a recognised history of introductions (Figure 3, orange highlights; Table S1). On average across the 39 individual papers undertaking in situ benthic surveys (e.g., excluding fish-only and NIMS only reports), 23.4% (± S.E. 3.7%) of all identified species (binomials) have a recognised history of introductions.

Twenty-six papers explicitly acknowledged the presence of NIMS in their examinations (Table 1). In the 39 in situ benthic papers (e.g., excluding fish-only and NIMS only reports), 15.6% (± S.E. 2.5%) of all identified species (binomials) were NIMS in the surveyed location.

Many of the 897 taxa identified from O&G structures have wide global distributions (particularly fish and deep sea species) and 511 are found in Australia. One hundred of the 179 species with a history of introductions are found in Australia as NIMS (90) or as cryptogenic species (10; i.e., species with an unknown origin). Eighteen species are identified as “invasive” pests in at least one jurisdiction, including seven in Western Australia (DPIRD) and 3 in Victoria (VicEPA) (Table S1).

Table 1: Identified papers with sufficient benthic species information. Locations are based on Marine Ecoregions of the World (MEOW, Spalding et al. 2007). "# Taxa" - all unique taxa; "#Spp" - the number of unique binomials; "w/IH" – the number of bin; see also Figure 2omials with a global invasion history; "NIMS" – the number of explicitly identified nonindigenous taxa in the study.

Reference	Location	MEOW	#Taxa	#Spp	w/IH	NIMS	Structure Type
Albano et al. 2016	Arabian (Persian) Gulf	90	69	33	6	1	platform
Bell and Smith 1999	North Sea	25	1	1	0	0	platform
Benech 1978	S California Bight	59	1	1	0	0	semisubmersible
Benfield et al. 2019	N Gulf of Mexico	43	5	5	0	0	platform
Bond et al. 2018a	Exmouth to Broome	144	108	98	11	0	pipeline
Bond et al. 2018b	Exmouth to Broome	144	27	24	5	0	pipeline
Bram et al. 2005	S California Bight	59	41	33	11	5	platform
Carlisle et al. 1964	S California Bight	59	29	27	5	0	platform
Coolen et al. 2018	North Sea	25	172	143	34	15	platform
Coolen et al. 2020a	North Sea	25	1	1	1	0	platform
Coolen et al. 2020b	North Sea	25	218	143	34	15	platform
Ferriera et al. 2006	Eastern Brazil	76	39	31	11	5	platform
Foster and Willan 1979[a]	Central New Zealand	199	12	12	8	12	platform
Friedlander et al. 2014	Gulf of Guinea South	85	41	20	10	5	platform
Gass and Roberts 2006	North Sea	25	1	1	0	0	platform
Huang et al. 1980	Yellow Sea	50	8	8	4	1	platform
Huang et al. 1994	Yellow Sea	50	4	2	0	0	platform
Kolian et al. 2017	N Gulf of Mexico	43	21	19	3	3	platform
Larcom et al. 2014	N Gulf of Mexico	43	1	1	0	0	platform
Love et al. 2012 [b]	S California Bight	59	13	12	0	0	platform
Love et al. 2019	S California Bight	59	43	15	0	0	platform
Martin and Lowe 2010 [b]	S California Bight	59	46	45	0	0	platform
McLean et al. 2017 [b]	Exmouth to Broome	144	91	77	12	0	pipeline
McLean et al. 2018 [b]	Exmouth to Broome	144	55	40	9	0	well head
McLean et al. 2021 [b]	Arafura Sea	139	168	129	14	0	pipeline
Page et al. 2006 [a]	S California Bight	59	3	2	2	2	Platform (jacket)
Page et al. 2019 [a]	S California Bight	59	1	1	1	1	platform
Pajuelo et al. 2016 [a,b]	Azores Canaries Madeira	29	8	8	2	8	jack-up rig
Ponti et al. 2002	Adriatic Sea	30	41	37	7	2	platform
Pradella et al. 2014[b]	Exmouth to Broome	144	27	23	3	0	well head
Redford et al. 2021	North Sea	25	63	30	0	0	pipeline
Reeves et al. 2017	N Gulf of Mexico	43	2	2	0	0	platform
Relini and Mori 1979 [a]	Adriatic Sea	30	1	1	1	0	platform
Relini et al. 1998	Adriatic Sea	30	62	54	27	13	platform
Rezek et al. 2018	N Gulf of Mexico	43	34	30	5	3	platform

Reference	Location	MEOW	#Taxa	#Spp	w/IH	NIMS	Structure Type
Rouse et al. 2019	North Sea	25	5	5	1	0	pipeline
Sammarco et al. 2004	N Gulf of Mexico	43	10	10	1	1	platform
Sammarco et al. 2014	N Gulf of Mexico	43	4	4	1	1	platform
Sammarco et al. 2015	N Gulf of Mexico	43	6	5	3	3	platform
Schulze et al. 2020	N Gulf of Mexico	43	14	13	10	9	platform
Simons et al. 2016 [a]	S California Bight	59	1	1	1	1	platform
Southgate and Myers 1985	Celtic Sea	26	35	34	10	2	platform
Thomson et al. 2018	Exmouth to Broome	144	31	17	4	0	platform
Todd et al. 2018	North Sea	25	43	35	6	0	platform
van der Strap et al. 2016	North Sea	25	17	16	3	1	platform
Venugopalan and Wagh 1990	Western India	103	69	36	16	6	platform
Whomersley and Picken 2003	North Sea	25	3	3	1	0	platform
Wanless et al. 2009[a]	Tristan Gough	189	51	23	22	0	platform
Wolfson et al. 1979	S California Bight	59	5	5	2	0	platform
Yan et al. 1998	Gulf of Tonkin	112	9	8	4	1	platform
Yan et al. 1999	Southern China	113	5	3	2	2	platform
Yan et al. 2006	Gulf of Tonkin	112	105	79	20	0	platform
Yeo et al. 2010	Sunda Shelf/Java Sea	117	27	26	3	50	semisubmersible

a – only reports NIMS

b – only reports fish to species level

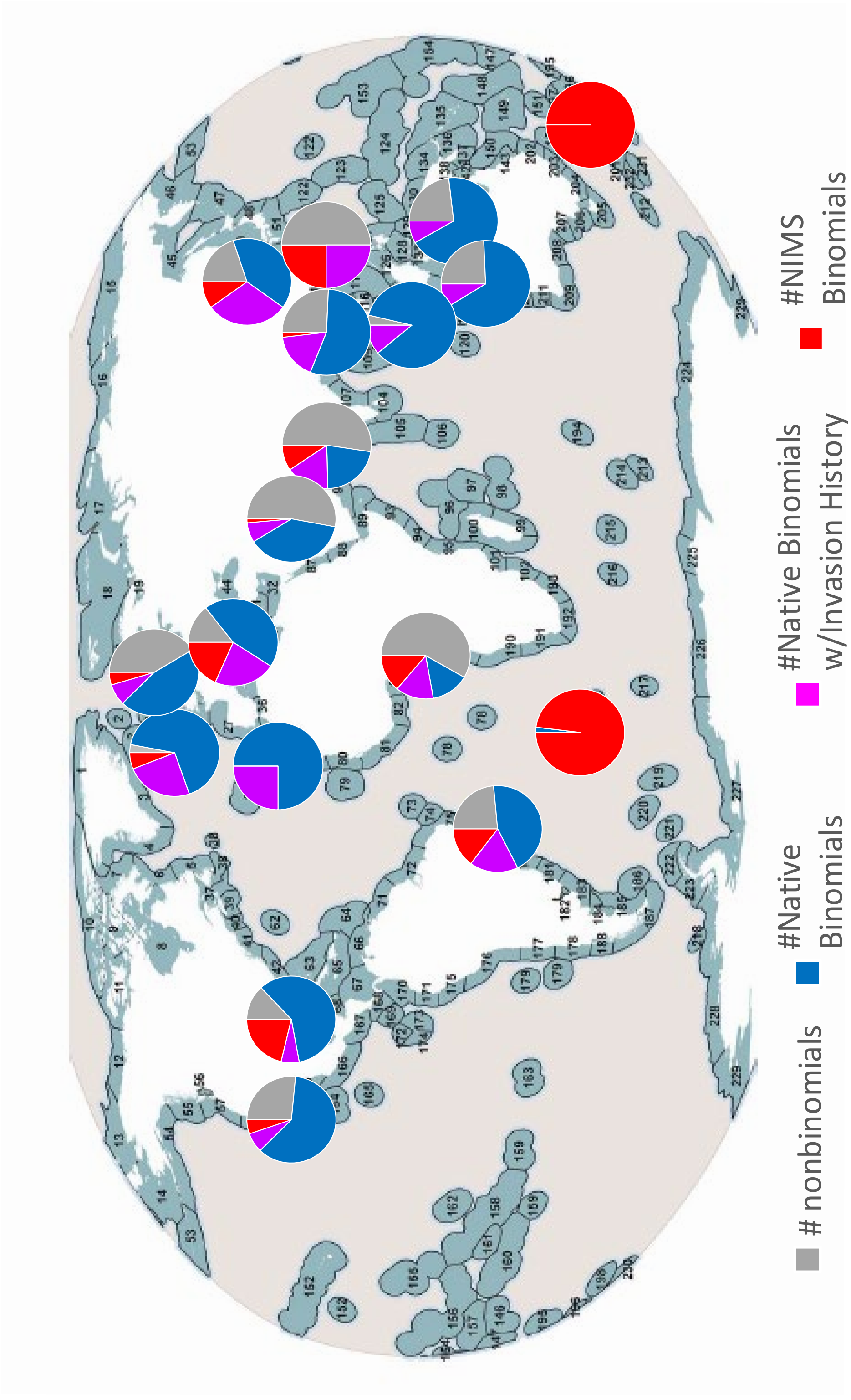

Figure 2: Taxa associated with offshore O&G structures across Marine Ecoregions of the World (base Figure from Spalding et al. 2007; numbers represent MEOW ecoregions). Some ecoregions represent multiple papers (see Table 1). Nonbinomials are taxa without species level identification and may represent multiple species in some papers; Native binomials are taxa with species level identification that are native without a history of invasions elsewhere; Native binomials w/ Invasion History are taxa with species level identification that are native in the study location but with a history of invasions elsewhere; NIMS binomials are taxa with species level identification that are identified as nonindigenous to that location.

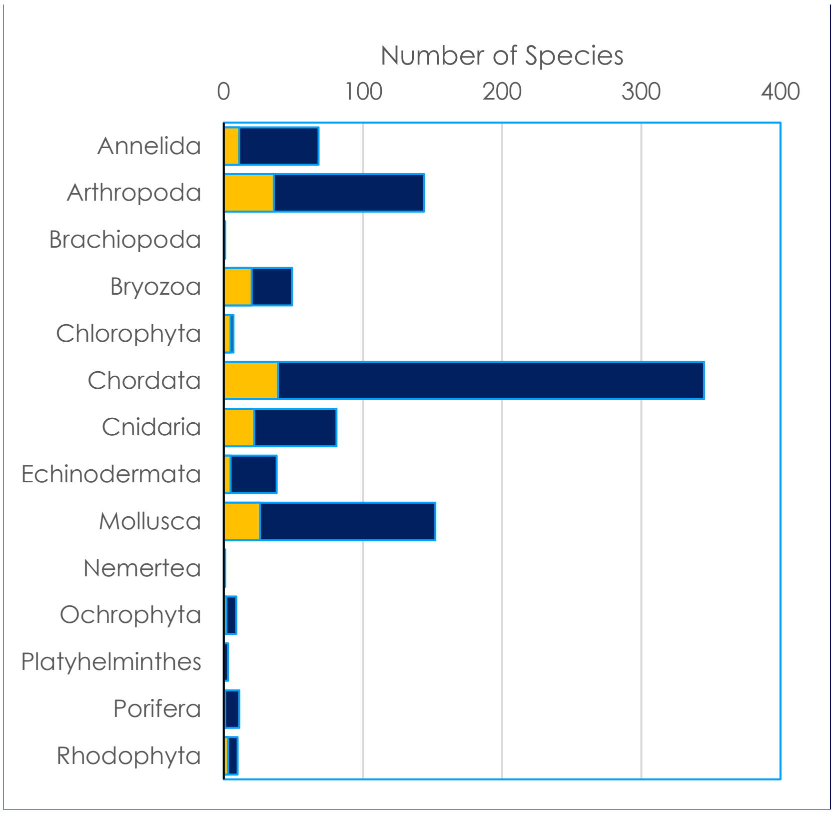

Figure 3: Phylogenetic distribution of marine taxa associated with offshore O&G structures in the 53 papers. Orange highlights the number of binomial taxa with recognised invasion history.

Life history traits

Depth distributions were obtained for 77.9% (699) of the 897 taxa identified from O&G structures (Figure 4). Ninety-five (13.6%) were restricted to waters less than 25 m, 245 (35.1%) to waters less than 50 m deep, and 400 (57.2%) to waters less than 100 m deep (Figure 4). The depth distribution of species with an invasion history and the 18 species deemed to be invasive was similar (Figure 4), however invasive species were more likely to be restricted to shallow waters (<100m). Seven invasive species (38.9%) were restricted to waters less than 50 m and 14 (77.8%) to waters less than 100 m deep (Figure 4).

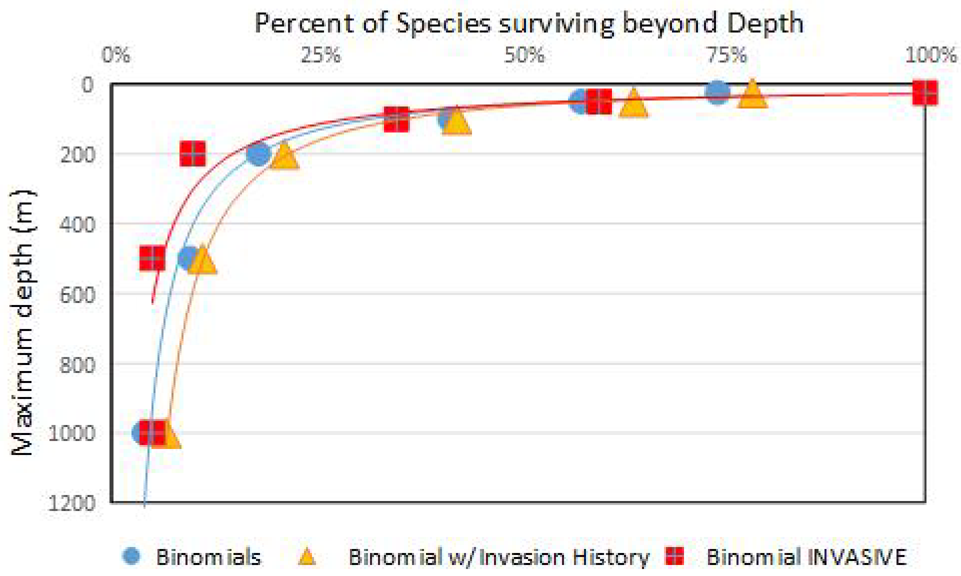

Figure 4: The percent of species surviving by depth distributions based on OBIS, FishBase and SeaLifeBase. Global species associated with O&G structures (Binomials Blue – $y = 27.35x^{1.05}$; R^2 0.949); with an invasion history (Orange - $y = 23.67x^{1.4}$; R^2 0.984); B); and Invasive species (Red - $y = 24.87x^{1.21}$; R^2 0.969).

The time that larvae of benthic species spend in the water column prior to settlement (Pelagic Larval Duration – PLD) provides a prediction of potential passive (current) dispersal. PLDs were obtained for 19.4% (174) of the 897 taxa identified from O&G structures, including 113 (63.1%) of the 179 species with an invasion history and 97 deemed to be invasive (Figure 5). Overall, twenty-two binomial species (12.6%) had PLDs less than 7 days, with 307 (53.8%) with PLDs less than 35 days (Figure 4). In contrast, shorter PLDs were associated with species that have an invasion history (49.6% PLDs <21 days) and invasive binomial species (45.4% PLDs <21 days) (Figure 5).

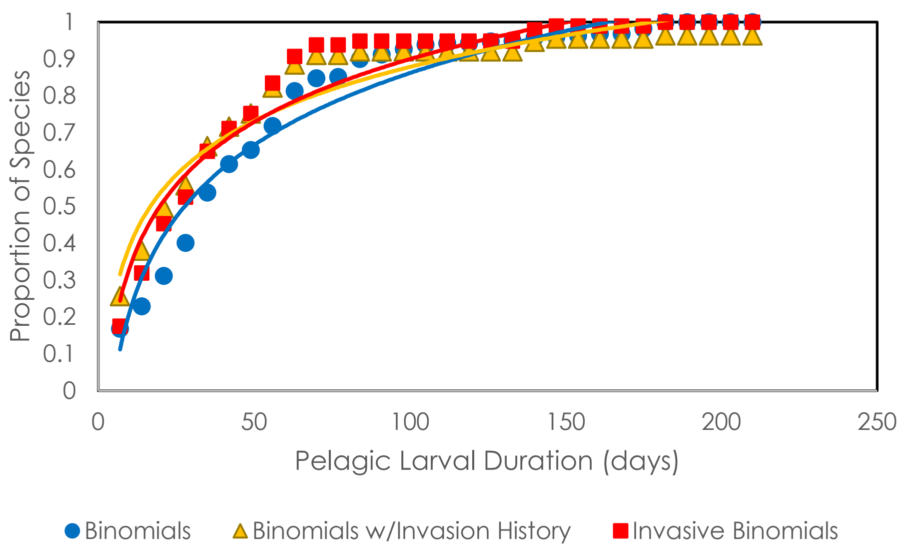

Figure 5: The proportion of species with Pelagic Larval Durations (PLDs) less than time periods based on data from OBIS, FishBase and SeaLifeBase. Global species associated with O&G structures

(Binomials Blue – y = 0.2819ln(x) - 0.4368; R^2 0.946; with an invasion history Orange – y=0.2115ln(x) - 0.0959; R^2 0.917; invasive binomials Red - y = 0.2464ln(x) - 0.2354; R^2 = 0.917.

Evaluation of decommissioning scenarios

The decommissioning scenarios were assessed for the changed likelihood of transfer, survival and spread relative to the baseline decommissioning scenario of "leaving structures intact and in place" (Figure 6a). This included assessment of the decommissioning actions required to dismantle, relocate or remove structures relative to the life history characteristics and traits of NIMS associated with O&G structures.

The action of cutting or dismantling of structures will likely result in the release of larvae due to induced spawning, creation of dislodged adult material some of which will likely become tychoplankton (benthic species accidentally swept into the plankton that remain suspended due to neutral buoyancy) or become droops that fall to the seafloor. While this action is unlikely to create any additional footprint of material, it will create a high density of release and therefore enhance the "cloud" of larvae or material produced. It remains unlikely that this action alone will expose additional areas to NIMS (Table 2).

The action of toppling or reefing material in place will broaden the footprint of exposure, depending on the distances of structures from the original placement (Figure 6b and c). If these structures are placed below the maximum depth distribution of NIMS present on the structure, then the transfer and survival risk would be minimized (Table 2).

The action of moving the structure to another location, either by towing or by lifting onto a vessel, will enhance the potential for material to be released (triggered spawning) or droop from the structure, resulting on a much larger footprint (Figure 6d) and increase the likelihood of a suitable habitat being infected (Table 2).

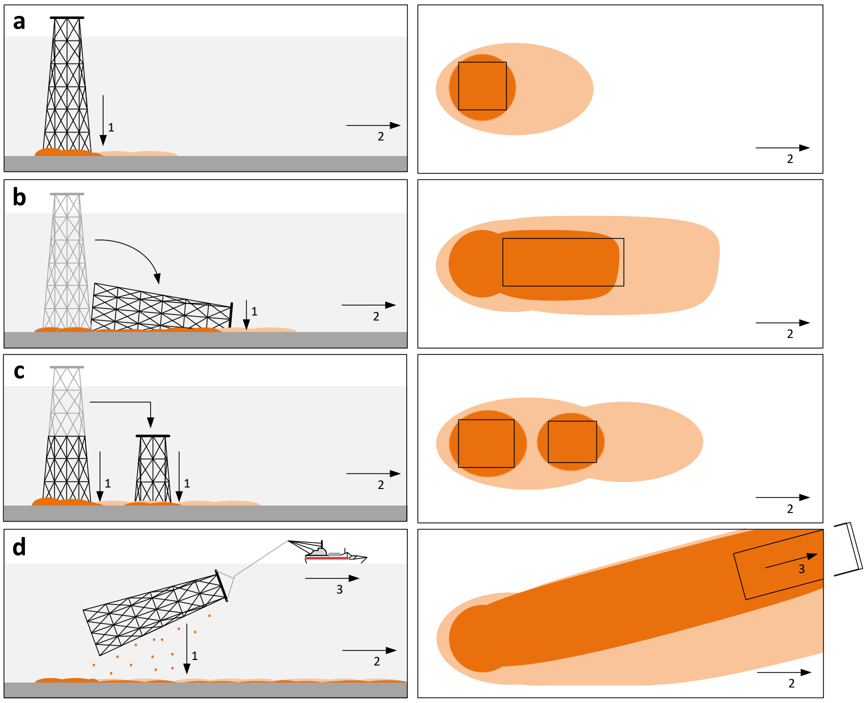

Figure 6: Decommissioning scenarios a) leave structure in place; b) leave structure in place, cut and topple; c) partial removal of platform or reefing; d) tow and place. Arrow 1 represents gravity fall of material dislodge from structures; Arrow 2 represents current direction, Arrow 3 represents towing

vessel direction. Dark and light orange represent exposures of benthic habitats to biological material; right hand panels provide a top view illustrating dislodged biological material footprint (dark orange) and planktonic dispersal (light orange). Note these figures are not drawn to scale. (adapted from Bull and Love 2019).

Table 2: Decommissioning actions with potential impacts to NIMS, comparison with "leave in place" baseline and possible mitigation measures.

Decommissioning Action	**Potential NIMS transfer, survival and spread**	**Δ**	**Difference from "leave in place" baseline**	**Possible mitigation measures**
Intentional defouling of benthic material to at least 50 m	Triggered spawning (larval release), Creation of tychoplankton (adult species knocked into the plankton), Living material knocked off and transferred to the seabed.	=	Reduces long term persistence of NIMS	Not necessary as this is equivalent to baseline
Cutting of the structure to topple or dismantle	Vibration, scraping or defouling resulting in Triggered spawning (larval release), Creation of tychoplankton (adult species knocked into the plankton), Living material knocked off and transferred to the seabed.	↓	If reefed location is greater than the maximum depth of the species then reduces NIMS risk below baseline.	Not necessary unless transfer to a new location in which case intentional defouling of removed structure prior to removal
Cutting of the structure to remove top section	Vibration, scraping or defouling resulting in Triggered spawning (larval release), Creation of tychoplankton (adult species knocked into the plankton), Triggered spawning (larval release) as material dries on vessel during transit, Creation of tychoplankton (adult species knocked into the plankton) or droops during transit, Living material knocked off and transferred to the seabed during lifting out of water.	↑	Planktonic and falling material released across a larger distance during the tow	Defouling of removed structure prior to removal or enclose structure while on board
Toppling or placing the structure as a reef at depth	Living material transferred to depth on a reefed structure and to the seabed.	↓	If reefed location is greater than the maximum depth of the species then reduces NIMS risk below baseline.	Not necessary unless transfer to a new location in which case intentional defouling of removed structure prior to removal
		↑	If reefed location is less than the maximum depth of the species then increases NIMS below baseline.	Intentional defouling of removed structure

Removal by towing	Triggered spawning (larval release) during towed transit, Creation of tychoplankton (adult species knocked into the plankton) during towed transit, Living material knocked off and transferred to the benthos.	↑	Planktonic and falling material released across a larger distance during the tow	Defouling of removed structure prior to removal
Removal by lifting onto a vessel	Triggered spawning (larval release) as material dries on vessel during transit, Creation of tychoplankton (adult species knocked into the plankton) or droops during transit, Living material knocked off and transferred to the seabed during lifting out of water.	↑	Planktonic and falling material released across a larger distance during the tow	Defouling of removed structure prior to removal or enclose structure while on board

Conclusion

As oil and gas infrastructure reaches the end of life, decisions about which decommissioning option is most desirable will be based on a number of considerations. These are likely to include technical aspects such as feasibility and health and safety, economic aspects, social aspects such as aesthetic benefit or recreational fishing value, and environmental effects including the benefits of structures as reefs (e.g., Jagerroos and Krause 2016; van Elden et al. 2019, 2022), and the impacts of released materials and the transfer, survival and spread of nonindigenous marine species (NIMS; Sammarco et al. 2014; Page et al. 2019).

This report considered the relative impact of various decommissioning scenarios on changing the NIMS risk of transfer, survival and spread relative to the operational activity. This examination identified 1,344 unique taxa associated with benthic habitat on or near O&G structures (including fish). 897 taxa were identified to species level, of which 179 had a recognised history of introduction (not necessarily in the reported study location).

One hundred of the 179 species are introduced or cryptogenic in Australian waters and provide a suite to consider the relative risks of decommissioning scenarios. At least 18 of the 179 species are identified as invasive pests, though several others have recognised impacts, with 7 identified as pests in Australian waters.

Two ecological traits, depth distribution and time larvae spend in the water column, which could influence the residual risk of transfer or survival of species were examined. Analysis of the maximum depth distributions of species with an invasion history globally and invasive species (Figure 4) suggest that the majority of species are restricted to waters less than 100 m deep. The majority of invasive species present in Australian waters were restricted to shallow waters: seven species (38.9%) were restricted to waters less than 50 m and 14 (77.8%) to waters less than 100 m deep (Figure 4). This suggests that removing O&G structures at depths greater than 50 m and toppling the structure in water greater than 100 m will significantly reduce the survival of any invasive species or NIMS present.

The time larvae spend in the water column, or Pelagic Larval Duration (PLD), provides an estimate of passive dispersal when combined with local current information where high PLDs would infer a larger dispersal distance and therefore increased connectivity (see McLean et al. 2022). While PLD information was not available for a large number of species associated with O&G structures in this study, shorter PLDs were associated with species that have an invasion history (49.6% PLDs <21 days) and invasive binomial species (45.4% PLDs <21 days) (Figure 5).

Examination of the decommissioning scenarios suggest that “leaving structures in place” creates the least change in risk of NIMS transfer, survival or spread. The potential for natural (not human mediated) spread would likely be unchanged once operational activity ceased. This scenario however would provide no reduction in residual NIMS risk without an intensive defouling program to remove any biofouling material on the structures to at least 50 m depth.

In contrast, if the structure is in sufficiently deep water beyond the maximum depth limits of NIMS or invasive species present (>100 m), then a topple in place would present the greatest reduction in NIMS or invasive species risk as it does not increase the footprint from baseline, and it minimizes survival of existing species due to depth limitations.

The decommissioning action of cutting an O&G structure could potentially trigger a spawning event and release biofouling material as tychoplankton or to the seabed. Cutting an O&G structure >50 m would substantially reduce the risk of leaving intact NIMS or invasive species populations: alternatively cutting at >25 m but <50 m would potentially leave intact NIMS or invasive species populations, however defouling of this material could provide significant reduction in NIMS risk. All scenarios that involve relocating structures either by towing or on-board a vessel, increase the likelihood of NIMS and invasive species spread to new locations.

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Table S1: Species associated with benthic habitats of O&G structures that also have a history of invasion with records of the number of Studies identified in this project and the representative MEOW Provinces and Ecoregions (Spalding et al. 2007); The status of species in Australia is presented based on all records, not restricted to O&G structures (NIMS – Nonindigenous Marine Species; CRYPTO – cryptogenic species with unknown status; Native – considered endemic to Australia; NP – Not present in Australia). **BOLD** Species are recognised as potential or existing invasive pests in any global jurisdiction; underlined are recognized as potential or existing invasive pests in at least one Australian jurisdiction. Footnotes highlight location of Invasive or Pest species declaration.

Phylum	Class	Order	Confirmed Genus species	Confirmed Authority	WoRMS ID	# Studies	# MEOW Provinces	# MEOW Ecoregions	Status in AUS
Annelida	Polychaeta	Eunicida	*Marphysa sanguinea*	(Montagu 1813)	130075	1	1	1	NIMS
Annelida	Polychaeta	Phyllodocida	*Alitta succinea*	(Leuckart 1847)	234850	1	1	1	NIMS
Annelida	Polychaeta	Phyllodocida	*Eulalia viridis*	(Linnaeus, 1767)	130639	2	1	1	CRYPTO
Annelida	Polychaeta	Phyllodocida	*Eumida sanguinea*	(Örsted, 1843)	130644	2	1	1	Native
Annelida	Polychaeta	Phyllodocida	*Harmothoe spinifera*	(Ehlers 1864)	130781	1	1	1	CRYPTO
Annelida	Polychaeta	Phyllodocida	*Phyllodoce longipes*	Kinberg 1866	130673	1	1	1	NIMS
Annelida	Polychaeta	Phyllodocida	*Syllis gracilis*	Grube, 1840	131435	4	3	3	NIMS
Annelida	Polychaeta	Sabellida	***Ficopomatus enigmaticus***[1]	(Fauvel 1923)	130988	1	1	1	NIMS
Annelida	Polychaeta	Sabellida	***Hydroides dianthus***[2]	(Verril 1873)	131000	1	1	1	NP
Annelida	Polychaeta	Sabellida	*Hydroides elegans*	(Haswell 1883)	131002	1	1	1	NIMS
Annelida	Polychaeta	Sabellida	*Hydroides ezoensis*	Okuda 1934	131003	1	1	1	NIMS
Annelida	Polychaeta	Sabellida	*Hydroides norvegica*	Gunnerus 1768	131009	2	2	2	Native
Annelida	Polychaeta	Sabellida	*Salmacina tribranchiata*	(Moore 1923)	334720	1	1	1	NP
Annelida	Polychaeta	Spionida	*Polydora ciliata*	(Johnston, 1838)	131141	4	2	2	NIMS
Annelida	Polychaeta	Terebellida	*Lanice conchilega*	(Pallas, 1766)	131495	2	1	1	NIMS?
Arthropoda	Insecta	Diptera	*Telmatogeton japonicus*	Tokunaga 1933	118154	1	1	1	NP
Arthropoda	Malacostraca	Amphipoda	*Caprella californica*	Stimpson 1856	394864	1	1	1	NP

[1] Brazil, Argentina
[2] European Union

Phylum	Class	Order	*Confirmed Genus species*	Confirmed Authority	WoRMS ID	# Studies	# MEOW Provinces	# MEOW Ecoregions	Status in AUS
Arthropoda	Malacostraca	Amphipoda	*Caprella equilibra*	Say 1818	101824	3	3	3	NIMS
Arthropoda	Malacostraca	Amphipoda	***Caprella mutica***[3]	Schurin 1935	146768	3	2	2	NIMS
Arthropoda	Malacostraca	Amphipoda	*Caprella verrucosa*	Boeck 1871	430930	1	1	1	NP
Arthropoda	Malacostraca	Amphipoda	*Ericthonius brasiliensis*	(Dana 1853)	102401	1	1	1	NP
Arthropoda	Malacostraca	Amphipoda	*Hyperia galba*	(Montagu, 1813)	103251	2	1	1	NIMS
Arthropoda	Malacostraca	Amphipoda	*Monocorophium acherusicum*	(Costa, 1853)	225814	2	1	1	NIMS
Arthropoda	Malacostraca	Amphipoda	*Monocorophium sextonae*	(Crawford 1937)	148603	3	2	2	NIMS
Arthropoda	Malacostraca	Amphipoda	*Paracaprella pusilla*	Meyer 1890	211364	1	1	1	NIMS
Arthropoda	Malacostraca	Amphipoda	*Podocerus brasiliensis*	(Dana 1853)	214744	1	1	1	NIMS
Arthropoda	Malacostraca	Amphipoda	*Stenothoe gallensis*	Walker 1904	103163	1	1	1	NP
Arthropoda	Malacostraca	Amphipoda	*Stenothoe valida*	Dana, 1852	103175	3	1	2	NIMS
Arthropoda	Malacostraca	Decapoda	*Cancer pagurus*	Linnaeus, 1758	107276	5	1	2	NIMS
Arthropoda	Malacostraca	Decapoda	*Carupa tenuipes*	Dana 1852	208760	1	1	1	Native
Arthropoda	Malacostraca	Decapoda	***Charybdis (Charybdis) hellerii***[4]	(A. Milne-Edwards 1867)	107382	2	2	2	NIMS
Arthropoda	Malacostraca	Decapoda	*Glabropilumnus seminudus*	(Miers 1884)	394939	1	1	1	Native
Arthropoda	Malacostraca	Decapoda	*Schizophrys aspera*	(H. Milne Edwards 1831)	210145	1	1	1	Native
Arthropoda	Malacostraca	Decapoda	*Sphaerozius nitidus*	Stimpson 1858	107411	1	1	1	NP
Arthropoda	Malacostraca	Decapoda	*Thalamita gloriensis*	Crosnier 1962	107406	1	1	1	NIMS
Arthropoda	Malacostraca	Isopoda	*Jassa falcata*	(Montagu 1808)	102431	1	1	1	NP
Arthropoda	Malacostraca	Isopoda	*Jassa marmorata*	Holmes, 1905	102433	3	2	2	NIMS

[3] United Kingdom
[4] New Zealand

Phylum	Class	Order	*Confirmed Genus species*	Confirmed Authority	WoRMS ID	# Studies	# MEOW Provinces	# MEOW Ecoregions	Status in AUS
Arthropoda	Thecostraca	Balanomorpha	*Amphibalanus amphitrite*	(Darwin, 1854)	421137	4	4	4	NIMS
Arthropoda	Thecostraca	Balanomorpha	***Amphibalanus eburneus***[5]	(Gould 1841)	421138	1	1	1	NIMS
Arthropoda	Thecostraca	Balanomorpha	***Amphibalanus improvisus***	(Darwin 1854)	421139	4	3	3	NIMS
Arthropoda	Thecostraca	Balanomorpha	*Amphibalanus reticulatus*	(Utinomi 1967)	421140	4	3	4	NIMS
Arthropoda	Thecostraca	Balanomorpha	*Amphibalanus variegatus*	(Darwin 1854)	467513	1	1	1	NIMS
Arthropoda	Thecostraca	Balanomorpha	***Austrominius modestus***[6]	(Darwin, 1854)	712167	2	1	1	Native
Arthropoda	Thecostraca	Balanomorpha	*Balanus trigonus*	Darwin 1854	106223	6	4	4	NIMS
Arthropoda	Thecostraca	Balanomorpha	*Fistulobalanus albicostatus*	(Pilsbry 1916)	535166	1	1	1	NP
Arthropoda	Thecostraca	Balanomorpha	*Megabalanus californicus*	(Pilsbry 1916)	394981	1	1	1	NP
Arthropoda	Thecostraca	Balanomorpha	*Megabalanus coccopoma*	(Darwin, 1854)	149682	4	3	3	NIMS
Arthropoda	Thecostraca	Balanomorpha	*Megabalanus rosa*	Pilsbry 1916	394983	2	2	2	NIMS
Arthropoda	Thecostraca	Balanomorpha	*Megabalanus tintinnabulum*	(Linnaeus 1758)	106225	5	5	5	NIMS
Arthropoda	Thecostraca	Balanomorpha	*Megabalanus volcano*	(Pilsbry 1916)	212570	2	2	2	NIMS
Arthropoda	Thecostraca	Balanomorpha	*Tetraclita japonica japonica*	(Pilsbry 1916)	535535	1	1	1	NIMS
Arthropoda	Thecostraca	Scalpellomorpha	*Conchoderma auritum*	(Linnaeus 1767)	106146	1	1	1	NIMS
Arthropoda	Thecostraca	Scalpellomorpha	*Conchoderma virgatum*	Spengler 1790	106147	2	2	2	NIMS
Arthropoda	Thecostraca	Scalpellomorpha	*Lepas (Anatifera) anatifera*	Linnaeus 1767	733346	2	2	2	NIMS
Arthropoda	Thecostraca	Scalpellomorpha	*Lepas (Anatifera) anserifera*	Linnaeus 1767	733347	3	2	3	NIMS
Bryozoa	Gymnolaemata	Cheilostomatida	*Aetea anguina*	(Linnaeus 1758)	111062	1	1	1	NIMS
Bryozoa	Gymnolaemata	Cheilostomatida	*Aspidelectra melolontha*	(Landsborough 1852)	111350	1	1	1	NP

[5] Western Australia
[6] United Kingdom

Phylum	Class	Order	*Confirmed Genus species*	Confirmed Authority	WoRMS ID	# Studies	# MEOW Provinces	# MEOW Ecoregions	Status in AUS
Bryozoa	Gymnolaemata	Cheilostomatida	*Biflustra grandicella*	(Canu & Bassler 1929)	396709	2	2	2	NIMS
Bryozoa	Gymnolaemata	Cheilostomatida	*Biflustra savartii*	(Audouin 1826)	396712	2	2	2	NIMS
Bryozoa	Gymnolaemata	Cheilostomatida	*Bugula neritina*	(Linnaeus 1758)	111158	2	2	2	NIMS
Bryozoa	Gymnolaemata	Cheilostomatida	*Bugulina stolonifera*	(Ryland 1960)	834018	1	1	1	NIMS
Bryozoa	Gymnolaemata	Cheilostomatida	*Celleporella hyalina*	(Linnaeus, 1767)	111397	3	2	2	NIMS
Bryozoa	Gymnolaemata	Cheilostomatida	*Conopeum reticulum*	(Linnaeus, 1767)	111351	2	1	1	NIMS
Bryozoa	Gymnolaemata	Cheilostomatida	*Electra pilosa*	(Linnaeus, 1767)	111355	2	1	1	Native
Bryozoa	Gymnolaemata	Cheilostomatida	*Fenestrulina delicia*	Winston, Hayward & Craig 2000	408266	1	1	1	NP
Bryozoa	Gymnolaemata	Cheilostomatida	*Hippopodina feegensis*	(Busk 1884)	111389	1	1	1	Native
Bryozoa	Gymnolaemata	Cheilostomatida	*Membranipora membranacea*	(Linnaeus 1767)	111411	1	1	1	CRYPTO
Bryozoa	Gymnolaemata	Cheilostomatida	*Microporella ciliata*	(Pallas, 1766)	111421	4	2	2	NIMS
Bryozoa	Gymnolaemata	Cheilostomatida	*Schizoporella errata*	(Waters 1878)	111527	4	3	3	NIMS
Bryozoa	Gymnolaemata	Cheilostomatida	*Schizoporella unicornis*	(Johnston in Wood, 1844)	111538	2	2	2	NIMS
Bryozoa	Gymnolaemata	Cheilostomatida	*Scruparia ambigua*	(d'Orbigny, 1841)	111539	2	1	1	NIMS
Bryozoa	Gymnolaemata	Cheilostomatida	*Scrupocellaria scruposa*	(Linnaeus, 1758)	111250	1	1	1	NIMS
Bryozoa	Gymnolaemata	Cheilostomatida	*Smittoidea prolifica*	Osburn 1952	396735	1	1	1	NP
Bryozoa	Gymnolaemata	Cheilostomatida	*Watersipora subatra*	(Ortmann 1890)	816025	1	1	1	NP
Bryozoa	Gymnolaemata	Cheilostomatida	*Watersipora subtorquata*	(d'Orbigny 1852)	111592	2	1	1	NIMS
Chlorophyta	Ulvophyceae	Bryopsidales	*Bryopsis pennata*	J.V. Lamouroux 1809	144456	1	1	1	NIMS
Chlorophyta	Ulvophyceae	Bryopsidales	*Bryopsis plumosa*	(Hudson) C.Agardh 1823	144457	1	1	1	NIMS
Chlorophyta	Ulvophyceae	Ulvales	*Ulva intestinalis*	Linnaeus 1753	234471	2	2	2	NIMS
Chlorophyta	Ulvophyceae	Ulvales	*Ulva lactuca*	Linnaeus 1753	145984	3	2	3	NIMS

Phylum	Class	Order	*Confirmed Genus species*	Confirmed Authority	WoRMS ID	# Studies	# MEOW Provinces	# MEOW Ecoregions	Status in AUS
Chlorophyta	Ulvophyceae	Ulvales	*Ulva rigida*	C.Agardh 1823	145990	1	1	1	NIMS
Chordata	Actinopteri		*Dascyllus trimaculatus*	(Rüppell 1829)	212846	1	1	1	Native
Chordata	Actinopteri		*Lutjanus argentimaculatus*	(Forsskål 1775)	218498	4	1	1	Native
Chordata	Actinopteri		*Lutjanus sebae*	(Cuvier 1816)	218499	7	2	2	Native
Chordata	Actinopteri		*Scarus ghobban*	Forsskål 1775	219127	3	2	2	Native
Chordata	Actinopteri	Acanthuriformes	*Acanthurus coeruleus*	Bloch & Schneider 1801	159581	1	1	1	NP
Chordata	Actinopteri	Acanthuriformes	*Heniochus acuminatus*	(Linnaeus 1758)	218765	3	1	1	Native
Chordata	Actinopteri	Acanthuriformes	*Platax teira*	(Forsskål 1775)	218710	2	1	1	NP
Chordata	Actinopteri	Acanthuriformes	*Pomacanthus imperator*	(Bloch 1787)	220001	4	1	1	Native
Chordata	Actinopteri	Acanthuriformes	*Pomacanthus semicirculatus*	(Cuvier 1831)	220003	1	1	1	Native
Chordata	Actinopteri	Aulopiformes	*Saurida undosquamis*	(Richardson 1848)	126371	2	2	2	Native
Chordata	Actinopteri	Carangifornes	*Rachycentron canadum*	(Linnaeus 1766)	127006	3	2	2	Native
Chordata	Actinopteri	Centrarchiformes	*Terapon jarbua*	(Forsskål 1775)	218350	1	1	1	Native
Chordata	Actinopteri	Centrarchiformes	*Terapon theraps*	Cuvier 1829	218349	1	1	1	Native
Chordata	Actinopteri	Holocentriformes	*Sargocentron rubrum*	(Forsskål 1775)	126400	2	2	2	Native
Chordata	Actinopteri	Kurtiformes	*Ostorhinchus fasciatus*	(White 1790)	712656	1	1	1	Native
Chordata	Actinopteri	Mulliformes	*Upeneus moluccensis*	(Bleeker 1855)	126989	1	1	1	Native
Chordata	Actinopteri	Ovalenttaria	*Abudefduf saxatilis*	(Linnaeus 1758)	159288	1	1	1	Native
Chordata	Actinopteri	Perciformes	*Cyclopterus lumpus*	Linnaeus 1758	127214	1	1	1	NP
Chordata	Actinopteri	Perciformes	*Epinephelus areolatus*	(Forsskål 1775)	218204	5	2	2	Native
Chordata	Actinopteri	Perciformes	*Epinephelus chlorostigma*	(Valenciennes 1828)	218199	2	1	1	Native
Chordata	Actinopteri	Perciformes	*Epinephelus coioides*	(Hamilton 1822)	218200	4	2	2	Native
Chordata	Actinopteri	Perciformes	*Epinephelus fasciatus*	(Forsskål 1775)	218207	2	2	2	Native

Phylum	Class	Order	*Confirmed Genus species*	Confirmed Authority	WoRMS ID	# Studies	# MEOW Provinces	# MEOW Ecoregions	Status in AUS
Chordata	Actinopteri	Perciformes	*Epinephelus malabaricus*	(Bloch & Schneider 1801)	218206	4	2	2	Native
Chordata	Actinopteri	Perciformes	*Epinephelus merra*	Bloch 1793	218228	1	1	1	Native
Chordata	Actinopteri	Perciformes	*Epinephelus quoyanus*	(Valenciennes 1830)	273867	1	1	1	Native
Chordata	Actinopteri	Perciformes	***Pterois miles***[7]	(Bennett 1928)	218077	1	1	1	Native
Chordata	Actinopteri	Perciformes	***Pterois volitans***[8]	(Linnaeus 1758)	159559	2	2	2	Native
Chordata	Actinopteri	Syngnathiformes	*Fistularia commersonii*	Rüppell 1838	217966	1	1	1	NP
Chordata	Actinopteri	Tetraodontiformes	*Lagocephalus sceleratus*	(Gmelin 1789)	219954	1	1	1	Native
Chordata	Ascidiacea	Aplausobranchia	*Didemnum candidum*	Savigny 1816	146902	1	1	1	NIMS
Chordata	Ascidiacea	Aplausobranchia	***Didemnum perlucidum***[9]	Monniot F. 1983	212506	1	1	1	NP
Chordata	Ascidiacea	Aplousobranchia	***Diplosoma listerianum***[10]	(Milne Edwards, 1841)	103579	5	4	4	NIMS
Chordata	Ascidiacea	Aplousobranchia	*Lissoclinum fragile*	(Van Name 1902)	250786	1	1	1	NP
Chordata	Ascidiacea	Phlebobranchia	*Phallusia nigra*	Savigny 1816	103725	1	1	1	NIMS
Chordata	Ascidiacea	Phlebobranchia	*Styela plicata*	(Lesueur 1823)	103936	1	1	1	NIMS
Chordata	Ascidiacea	Stolidobranchia	*Botrylloides leachii*	(Savigny 1816)	250081	1	1	1	NIMS
Chordata	Ascidiacea	Stolidobranchia	*Botryllus schlosseri*	(Pallas, 1766)	103862	1	1	1	NIMS
Chordata	Ascidiacea	Stolidobranchia	*Symplegma brackenhielmi*	(Michaelsen 1904)	251435	1	1	1	NIMS
Cnidaria	Anthozoa	Actiniaria	*Diadumene cincta*	Stephenson, 1925	100872	3	1	1	NP
Cnidaria	Anthozoa	Actiniaria	*Diadumene leucolena*	(Verill 1866)	158230	1	1	1	NP
Cnidaria	Anthozoa	Actiniaria	*Diadumene lineata*	(Verrill 1869)	395099	1	1	1	NIMS

[7] United States
[8] United States
[9] Western Australia
[10] Western Australia

Phylum	Class	Order	*Confirmed Genus species*	Confirmed Authority	WoRMS ID	# Studies	# MEOW Provinces	# MEOW Ecoregions	Status in AUS
Cnidaria	Anthozoa	Actiniaria	***Metridium dianthus***[11]	(Ellis 1768)	158251		1	1	Native
Cnidaria	Anthozoa	Alcyonacea	***Carijoa riisei***[12]	(Duchassaing & Michelotti 1860)	395098	3	3	3	Native
Cnidaria	Anthozoa	Corallimorpharia	*Corynactis californica*	Carlgren 1936	283836	2	1	1	NP
Cnidaria	Anthozoa	Scleractinia	*Caryophyllia (Caryophyllia) smithii*	Stokes & Broderip 1828	135144	1	1	1	CRYPTO
Cnidaria	Anthozoa	Scleractinia	***Tubastraea coccinea***[13]	Lesson 1830	291251	7	2	2	Native
Cnidaria	Anthozoa	Scleractinia	***Tubastraea micranthus***[14]	(Ehrenberg 1834)	291255	3	1	1	Native
Cnidaria	Hydrozoa	Anthoathecata	*Coryne pusilla*	Gaertner, 1774	117471	1	1	1	NIMS
Cnidaria	Hydrozoa	Anthoathecata	*Ectopleura crocea*	(Agassiz 1862)	117981	2	2	2	NIMS
Cnidaria	Hydrozoa	Anthoathecata	*Ectopleura larynx*	(Ellis & Solander, 1786)	157933	5	1	2	NIMS
Cnidaria	Hydrozoa	Anthoathecata	*Eudendrium carneum*	Clarke 1882	117545	1	1	1	NIMS
Cnidaria	Hydrozoa	Anthoathecata	*Garveia franciscana*	(Browne 1907)	183171	1	1	1	NIMS
Cnidaria	Hydrozoa	Anthoathecata	*Turritopsis nutricula*	McCrady 1857	117440	1	1	1	NIMS
Cnidaria	Hydrozoa	Leptothecata	*Aglaophenia pluma*	(Linnaeus 1758)	117283	1	1	1	CRYPTO
Cnidaria	Hydrozoa	Leptothecata	*Clytia gracilis*	(Sars, 1850)	117367	3	2	2	CRYPTO
Cnidaria	Hydrozoa	Leptothecata	*Clytia hemisphaerica*	(Linnaeus, 1767)	117368	4	3	3	NIMS
Cnidaria	Hydrozoa	Leptothecata	*Diphasia digitalis*	(Busk 1852)	220585	1	1	1	Native
Cnidaria	Hydrozoa	Leptothecata	*Filellum serratum*	(Clarke 1879)	117691	1	1	1	NIMS
Cnidaria	Hydrozoa	Leptothecata	*Gonothyraea loveni*	(Allman, 1859)	117377	2	1	1	NIMS

[11] Canada
[12] United States
[13] Brazil, Unites States
[14] Brazil, United States

Phylum	Class	Order	*Confirmed Genus species*	Confirmed Authority	WoRMS ID	# Studies	# MEOW Provinces	# MEOW Ecoregions	Status in AUS
Cnidaria	Hydrozoa	Leptothecata	*Halopteris diaphana*	(Heller 1868)	117632	1	1	1	CRYPTO
Cnidaria	Hydrozoa	Leptothecata	*Laodicea undulata*	(Forbes & Goodsir 1853)	117725	1	1	1	CRYPTO
Cnidaria	Hydrozoa	Leptothecata	*Obelia bidentata*	Clark, 1875	117385	3	2	2	Native
Cnidaria	Hydrozoa	Leptothecata	*Obelia dichotoma*	(Linnaeus, 1758)	117386	4	3	3	NIMS
Cnidaria	Hydrozoa	Leptothecata	*Obelia longissima*	(Pallas, 1766)	117389	2	1	1	NIMS
Cnidaria	Hydrozoa	Leptothecata	*Plumularia setacea*	(Linnaeus, 1758)	117824	1	1	1	NIMS
Cnidaria	Scyphozoa	Rhizostomeae	***Phyllorhiza punctata***[15]	von Lendenfeld 1884	135298	1	1	1	Native
Echinodermata	Asteroidea	Valvatida	*Hippasteria phrygiana*	(Parelius 1768)	124043	1	1	1	CRYPTO
Echinodermata	Echinoidea	Cidaroida	*Eucidaris tribuloides*	(Lamarck 1816)	396741	2	2	2	NP
Echinodermata	Ophiuroidea	Amphilepidida	*Ophiactis savignyi*	(Müller & Troschel 1842)	125122	3	3	3	Native
Mollusca	Bivalvia	Adapendonta	*Hiatella arctica*	(Linnaeus, 1767)	140103	8	5	6	NIMS
Mollusca	Bivalvia	Arcida	*Acar plicata*	(Dillwyn 1817)	215258	1	1	1	NIMS
Mollusca	Bivalvia	Arcida	*Anadara inaequivalvis*	(Bruguière 1789)	138785	1	1	1	NIMS
Mollusca	Bivalvia	Cardiida	*Fulvia fragilis*	(Forsskål in Niebuhr, 1775)	605733	1	1	1	NP
Mollusca	Bivalvia	Gastrochaenida	*Cucurbitula cymbium*	(Spengler 1783)	505332	1	1	1	Native
Mollusca	Bivalvia	Myida	***Varicorbula gibba***[16]	(Olivi 1792)	378492	1	1	1	NIMS
Mollusca	Bivalvia	Mytilida	*Mytilus edulis*	Linnaeus, 1758	140480	11	3	4	NIMS
Mollusca	Bivalvia	Mytilida	*Mytilus galloprovincialis*	Lamarck 1819	140481	4	3	3	NIMS

[15] European Union
[16] Victoria

Mollusca	Bivalvia	Mytilida	***Perna perna***[17]	(Linnaeus, 1758)	140483	1	1	1	NIMS (failed)
Phylum	Class	Order	*Confirmed Genus species*	Confirmed Authority	WoRMS ID	# Studies	# MEOW Provinces	# MEOW Ecoregions	Status in AUS
Mollusca	Bivalvia	Mytilida	*Septifer cumingii*	Récluz 1849	506176	1	1	1	Native
Mollusca	Bivalvia	Ostreida	*Hyotissa hyotis*	(Linnaeus 1758)	216636	1	1	1	Native
Mollusca	Bivalvia	Ostreida	*Isognomon legumen*	(Gmelin 1791)	208472	1	1	1	Native
Mollusca	Bivalvia	Ostreida	***Magellana gigas***[18]	(Thunberg 1793)	836033	4	3	3	NIMS
Mollusca	Bivalvia	Ostreida	***Ostrea edulis***[19]	Linnaeus 1758	140658	4	2	3	NIMS
Mollusca	Bivalvia	Ostreida	*Pinctada margaritifera*	(Linnaeus, 1758)	207899	1	1	1	Native
Mollusca	Bivalvia	Pectinida	*Anomia simplex*	d'Orbigny 1853	156737	1	1	1	NIMS
Mollusca	Bivalvia	Venerida	*Chama macerophylla*	Gmelin 1791	397039	1	1	1	NP
Mollusca	Bivalvia	Venerida	*Chama pacifica*	Broderip 1835	139120	2	1	1	Native
Mollusca	Bivalvia	Venerida	*Circenita callipyga*	(Born 1778)	181359	1	1	1	Native
Mollusca	Bivalvia	Venerida	*Gafrarium pectinatum*	(Linnaeus 1758)	141914	1	1	1	Native
Mollusca	Gastropoda	Littorinimorpha	***Crepidula fornicata***[20]	(Linnaeus, 1758)	138963	2	1	1	NP
Ochrophyta	Phaeophyceae	Ectocarpales	*Hincksia sandriana*	(Zanardini) P.C.Silva 1987	145440	1	1	1	NIMS
Ochrophyta	Phaeophyceae	Laminariales	*Macrocystis pyrifera*	(Linnaeus) C.Agardh 1820	232231	1	1	1	Native
Porifera	Calcarea	Leucosolenida	*Leucosolenia botryoides*	(Ellis & Solander, 1786)	132216	2	1	1	NIMS
Porifera	Demospongiae	Suberitida	*Halichondria (Halichondria) panicea*	(Pallas, 1766)	165853	2	1	1	NIMS

[17] Australia, Victoria
[18] Western Australia
[19] United States
[20] Australia, Victoria, Western Australia; United Kingdom

Phylum	Class	Order	*Confirmed Genus species*	Confirmed Authority	WoRMS ID	# Studies	# MEOW Provinces	# MEOW Ecoregions	Status in AUS
Rhodophyta	Floridiophyceae	Ceramiales	*Aglaothamnion tennuissimum*	(Bonnemaison) Feldmann-Mazoyer 1941	144501	1	1	1	NIMS
Rhodophyta	Floridiophyceae	Ceramiales	*Antithamnionella elegans*	(Berthold) J.H. Price & D.M. John 1986	144519	1	1	1	NP
Rhodophyta	Floridiophyceae	Corallinales	*Corallina officinalis*	Linnaeus 1758	145108	1	1	1	NIMS
Rhodophyta	Floridiophyceae	Gigartinales	*Hypnea spinella*	(C.Agardh) Kützing 1847	145635	1	1	1	CRYPTO
Sipuncula	Phascolosomotidea	Phascolosomatida	*Phascolosoma (Phascolosoma) scolops*	(Selenka & de Man 1883)	220541	1	1	1	NIMS

Table S2: Species identified as "invasive" or as a "pest" by Victoria or Western Australia (not only in association with O&G structures) and known presence in various geographies; BOLD Species are identified as associated with O&G structures.

State of declared pest	Phylum	Genus species	Established in Australia?	Established in Victoria	Established in WA?	Established in Bass Strait (Victoria)?	Established in North West Shelf (WA)?
VIC	Annelida	*Sabella spallanzanii*	Y	Y		Y	N
WA	Arthropoda	*Acartia (Acanthacartia) tonsa*	N		N		N
WA	Arthropoda	***Amphibalanus eburneus*** **(*syn. Balanus eburneus*)**	Y		Y	?	N
WA	Arthropoda	*Amphibalanus improvisus* (*syn. Balanus improvisus*)	Y		Y	N	N
WA	Arthropoda	*Balanus glandula*	N		N	N	N
WA	Arthropoda	*Callinectes sapidus*	N		N	N	N
WA	Arthropoda	*Carcinoscorpius rotundicauda*	N		N	N	N
VIC/WA	Arthropoda	*Carcinus maenas*	Y	Y	Y	Y	N
VIC/WA	Arthropoda	*Charybdis (Charybdis) japonica*	N	N	N	N	N
WA	Arthropoda	*Chthamalus proteus*	N		N	N	N
WA	Arthropoda	*Dikerogammarus villosus*	N		N	N	N
VIC	Arthropoda	*Eriocheir sinensis*	N	N		N	N
VIC	Arthropoda	*Hemigrapsus sanguineus*	N	N		N	N
VIC	Arthropoda	*Rhithropanopeus harisii*	N	N		N	N
WA	Chordata	*Acanthogobius flavimanus*	Y		N	N	N
WA	Chordata	***Didemnum perlucidum***	Y		Y	?	Y
WA	Chordata	***Didemnum spp.***	Y		Y	?	Y
WA	Chordata	*Didemnum vexillum*	N	N	N	N	N
WA	Cnidaria	*Blackfordia virginica*	N		N	N	N
WA	Ctenophora	*Beroe ovata*	N		N	N	N
VIC/WA	Echinodermata	*Asterias amurensis*	Y	Y	N	Y	N
WA	Mollusca	*Anadara transversa* (syn. *A. demiri*)	Y		N	?	N
VIC/WA	Mollusca	*Arcuatula senhousia (syn. Musculista senhousia)*	Y	Y	Y	?	N
WA	Mollusca	*Brachidontes pharaonis*	N		N	N	N

State of declared pest	Phylum	*Genus species*	Established in Australia?	Established in Victoria	Established in WA?	Established in Bass Strait (Victoria)?	Established in North West Shelf (WA)?
VIC	Mollusca	*Corbula (Potamocorbula) amurensis*	N	N		N	N
VIC/WA	Mollusca	*Corbula gibba* (syn. *Varicorbula gibba*)	Y	Y	N	?	N
WA	Mollusca	*Crassostrea ariakensis*	N		N	N	N
WA	Mollusca	***Magellana (Crassostrea) gigas***	Y		Y	Y	N
WA	Mollusca	*Crassostrea virginica*	N		N	N	N
VIC/WA	Mollusca	*Crepidula fornicata*	N	N	N	N	N
VIC	Mollusca	*Maoricolpus rosea*	Y	Y		Y	N
VIC	Mollusca	*Mya japonica*	Y	N		N	N
VIC	Mollusca	*Mytilopsis sallei*	N	N		N	N
VIC	Mollusca	*Perna canaliculus*	N	N		N	N
VIC	Mollusca	***Perna perna***	N	N		N	N
VIC	Mollusca	*Perna viridis*	N	N		N	N
VIC	Mollusca	*Rapana venosa*	N	N		N	N
WA	Porifera	*Cliona thoosina*	N		N	N	N
WA		*Bonnemaisonia hamifera*	N		N	N	N
VIC/WA	Chlorophyta	*Caulerpa taxifolia*	Y	N	N	N	N
WA	Chlorophyta	*Codium fragile* (syn. *C. fragile tomentosoides*)	Y		Y	Y	N
VIC	Ochrophyta	*Undaria pinnatifida*	Y	Y		Y	N

Table S3: Articles that were identified but for which the full article was not readily available.

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