The vertical distribution of fish on two offshore oil platforms

Thomas Tothill 21530074

Supervisors:

Prof. Jessica Meeuwig[1]

Prof. Richard Hobbs[2]

[1] Marine Future Lab, School of Biological Sciences, University of Western Australia, Crawley, WA 6009, Australia

[2] School of Biological Sciences, University of Western Australia, Crawley, WA 6009, Australia

Marine Ecology Progress Series

This thesis is submitted in partial fulfillment of the requirements for a

Master of Biological Sciences, specialising in Marine Biology

BIOL556 Research Dissertation

School of Biological Sciences

Faculty of Science

The University of Western Australia

May 2019

Word Count: 8752

THE UNIVERSITY OF
WESTERN AUSTRALIA
Achieve International Excellence

School of Biological Sciences

Faculty of Science Assignment Cover Sheet

Name/s and Student Number/s	☑ **Individual** ☐ **Group**
1. Thomas Tothill 21530074	**4.**
2.	**5.**
3.	**6.**

It will be assumed that all group members have equally participated in group assignments, unless other arrangements have been made to notify lecturer of participation levels.

UNIT CODE: BIOL5552 - 5555	UNIT NAME: Research Dissertation
UNIT COORDINATOR/LECTURER: Jan Hemmi, Mandy Ridley	DAY/TIME DUE: Monday 27th May, 2019. 5.pm
TITLE/TOPIC OF ASSIGNMENT: Final Research Thesis	WORD COUNT: 8752
	OFFICE USE ONLY:

The Faculty of Science adheres to the University Policy on Academic Dishonesty which constitutes misconduct and is dealt with under the University's Statute 17 (http://calendar.publishing.uwa.edu.au/latest/partc/stat17). These guidelines make reference to the following:

- **Cheating** in tests or examinations, e.g., copying from another student, or taking unauthorized materials into the test or examination room.
- **Plagiarism**, i.e., presenting another's work as though it were one's own, for instance quoting or paraphrasing someone else's opinions, arguments or research findings, whether published or unpublished (e.g., from a book or article, an internet site, or another student's assignment), without clear acknowledgement of the source. You may quote material from another source, but if you do so, the quotation must be word perfect and, in addition to citing the source reference in the usual manner, the beginning and end of the quotation must be clearly indicated by quotation marks. E.g. "quotation"
- **Falsifying results** of experiments or research studies.
- **Collusion**, e.g., writing an assignment jointly and submitting it as the work of one individual. Although discussion and co-operation are valuable in the pursuit of knowledge and understanding, any work submitted for assessment must be the individual's own work unless it is clearly designated a group project.
- **Helping someone else to commit any dishonest act** such as those listed above.

The consequences for misconduct can be severe, including exclusion from the university. All students are expected to make themselves aware of the definitions and policies relating to academic misconduct, (http://www.teachingandlearning.uwa.edu.au/staff/policies/conduct), and with any additional requirements or stipulations that may be provided by individual unit co-ordinators.

Late Assignments
There are penalties for late assignments. Refer to the unit outline for more information.

NO ASSIGNMENT WILL BE ACCEPTED UNLESS THE FOLLOWING DECLARATION IS SIGNED AND DATED

DECLARATION

I/We certify that I have read the University guidelines on Academic Misconduct. I/We certify that the assignment submitted online is my own work and that all material drawn from other sources has been fully acknowledged.

I/We certify that I am aware that the work submitted under this declaration is submitted to an online plagiarism detection service for analysis and that the work may be stored in a database either internal or external to the University. I/We have a photocopy or electronic copy of this assignment in my possession.

Sign:	Date: 27/05/19	Sign:	Date:
Sign:	Date:	Sign:	Date:
Sign:	Date:	Sign:	Date:

Submission date: 27/05/19

FACULTY OF SCIENCE

Abstract

Many offshore oil and gas platforms around the globe are reaching their end-of-life and will require decommissioning in the next few decades. Australian legislation stipulates complete removal of obsolete platforms, however *in situ* decommissioning is currently under consideration. Knowledge on the ecology of offshore platforms in Australia is limited and the subsequent consequences of decommissioning remain poorly understood. Remotely operated vehicle (ROV) video is often collected during standard industry operations and may provide insight into the marine life associating with offshore platforms, however the utility of this video for scientific purposes remains unclear. Archival ROV video surveys of the Wandoo oil platforms on Australia's North West Shelf were tested for its utility and found that the imagery was limited in scientific value due to the haphazard method of collection. It is recommended that future surveys conduct standardised transects in high definition video at constant speeds and orientations. Based on a subset of the usable ROV video, the influence of depth and structural complexity on taxonomic richness, abundance, biomass and assemblage structure of fish populations was assessed on the Wandoo oil platforms. The two platforms, Wandoo A and Wandoo B, are situated in 54 m water and fish populations were assessed using vertical ROV video transects stratified into 10 m depth categories. Approximately 45% of observed taxa occurred only at depths <32 m and richness significantly declined with depth. Trends in abundance were more variable, however the number of individuals generally declined with depth to 40 m. Small reef fish were predominantly associated with complex habitat at depths <22 m, whilst large demersal species were abundant below 32 m and comprised the majority of biomass. Future decommissioning policy in Australia should consider the vertical distributions of fish populations and the importance of shallow sections of the platform.

Keywords: Oil and gas • Decommissioning • Remotely Operated Vehicle • Vertical distribution • Rigs-to-Reef • Platform ecology • Midwater habitat

Table of Contents

Acknowledgements

I would firstly like to thank both Vermillion Oil and Gas Australia and the University of Western Australia for funding for this project. I would like to thank my supervisors, Prof. Jessica Meeuwig and Prof. Richard Hobbs, for the time, effort and expertise they provided throughout the past 18 months. Without them I would have struggled immensely. I would like to acknowledge Sean van Elden for being the greatest mentor and taking on an un-official supervisory role. Everything I know about platform ecology came from Sean. The Marine Futures Lab manager, James Hehre, deserves a special mention. James, albeit prone to teasing students, is a managerial extraordinaire and the ability he has to consistently keep us master's students in line, on time and exceeding at what we do is commendable.

All the students, post-doctorate fellows and staff, both past and present, of the Marine Futures Lab deserve a warm thank you. The lab members kept me sane and became some great friends. I would like to thank Louis Masarei in particular, a past member of the Marine Futures Lab, for taking on a leadership role when I first began in the lab, teaching me the ropes of EventMeasure and putting in countless hours to help me identify cryptic species. I acknowledge Hanna Christ for keeping me organised and aiding with ArcGIS and photoshop, Alex McLennan for providing wisdom on referencing and the thesis submission process, and Tess Lyons for going through everything with me. Nikki de Campe, Claire Raphael, Adam Jolly, Vyvyan Summers, Jake Manger, Chris Thompson, Rachel White, Lincoln Hood and Naima Rodriguez Lopez all deserve a special mention.

1. Introduction

Offshore oil and gas platforms, including rigs, jackets, and wells, constitute a large proportion of the artificial structure within the world's marine environment. There are an estimated 12,000 offshore installations currently active on the continental shelves of 53 countries, and this number is predicted to continue rising (Ars & Rios 2017). This estimate includes approximately 4,000 oil and gas structures in the Gulf of Mexico (GOM) alone which have unintentionally created the world's largest artificial reef complex (Dauterive 2000, Ajemian et al. 2015). The addition of such large-scale marine infrastructure on ocean seabeds may have both positive and negative impacts on the local and regional marine ecology. The finite nature of hydrocarbon reservoirs imposes a productive timeframe on the extraction process, with over 85% of all offshore platforms expected to reach their end-of-life and require decommissioning within the next few decades (Parente et al. 2006). Considerations of the potential positive ecological impacts that operating structures generate is thus becoming particularly important as platforms approach the end of their operational lives and their removal is considered. The best practice for decommissioning, however, still has little international consensus.

The decommissioning process varies from nation-to-nation, however most countries favour complete removal of all supporting structures following the international guidelines set by the 1982 United Nations Convention on the Law of the Sea (UNCLOS) and the 1996 Protocol to the London Dumping Convention (London Protocol). Both pieces of legislation regulate the disposal and dumping of artificial structures at sea. Exceptions can be made to allow the disposal of obsolete platforms at sea, granted they fulfil some other legitimate purpose such as reef creation or biological conservation, as neither UNCLOS nor the London Protocol explicitly prohibit the decommissioning of structures *in situ* (Techera & Chandler 2015). The rigs-to-reef (RTR) program operating in the United States takes advantage of this provision and practices *in situ* decommissioning in the GOM and state of California. Under the RTR program, obsolete structures are essentially converted into artificial reefs to assist with benthic habitat construction, enhance biological activity, and avoid the loss of habitat that has accrued on the structures over the decades they were in place (Macreadie et al. 2011, Claisse et al. 2014, Fowler et al. 2015). Furthermore, platform conversions significantly reduce the cost of decommissioning to oil and gas companies and taxpayers alike (Sommer et al. 2019). The reefing (conversion) process can take on a number of forms and includes: (1) leaving the rig unaltered in its current standing position; (2) 'topping' the rig by dismantling and removing the top half of the structure, usually at 26 m below surface; (3) 'toppling the structure on its side in its current location; or (4) relocating the entire rig to another location, such as the deep sea (Schroeder & Love 2004, Macreadie et al. 2011).

The effectiveness of offshore structures acting as artificial habitats has been an area of ongoing discussion and a key reason for the lack of consensus on the best decommissioning practice. Much of this debate has centred around the attraction-production dichotomy outlined in Bohnsack (1989): does the addition of artificial structure in the water column increase secondary (fish) production, or does it simply attract fish from nearby natural reefs and thereby make them easier to exploit? It is likely that most artificial reefs both attract and produce fishes (Love et al. 2006), however empirical evidence to prove either argument is limited. Californian oil and gas platforms, however, have been shown to be among the most productive marine fish habitats globally (Claisse et al. 2014). The high vertical relief of offshore platforms creates a complex midwater habitat distinct from that of many natural reef systems and may provide a nursery for demersal larvae and pelagic juveniles (Love et al. 2006, 2012, Claisse et al. 2014). Settling fishes in midwater environments during their pelagic stage may find the addition of hard substrate throughout the water column more accessible than deeper surrounding natural reefs (Claisse et al. 2014). Reef-associated species, such as blacksmith (*Chromis punctipinnis*), have significantly higher densities in shallower portions of Californian platforms, suggesting that platform “topping” would result in decreased productivity of the species (Love et al. 2012). In regions where hydrocarbon extraction occurs in generally soft-bottom regions with few natural reefs, such as the southern Californian coast (Claisse et al. 2014) and GOM (Ajemian et al. 2015), the creation of new hard habitat may lead to a production benefit with attraction potentially less of a factor. Assessing the importance of the vertical relief provided by offshore platforms is crucial for the decision-making process involved in decommissioning, as ‘topping’ and ‘toppling’, two of the more common RTR techniques, effectively remove the midwater habitat and may impact ecosystem dynamics previously present on the active rig.

Part of the challenge in understanding potential positive outcomes of an RTR program is the lack of data. Targeted ecological research is an expensive enterprise, however a wealth of ecological information is collected for industry-related purposes such as maintenance inspections on infrastructure and environmental surveys. Remotely operated vehicle (ROV) video footage is commonly collected during standard industry operations. The ROV’s used for industry purposes are predominantly work-class, being tethered to the platform or vessel above via an umbilical connection cable and comprising of a camera(s) and multiple attachments for cleaning protocols, conductivity assessments and targeted inspections. The ecological value of

ROV video, which is often collected haphazardly, remains unclear. Video of this kind can allow scientists to 'look back in time' and assess ecosystem dynamics through a temporal lens (Macreadie et al. 2018), with archives often dating back to the original installation period. Several studies have opportunistically harnessed ROV footage used in routine oil and gas platform inspections for scientific purposes, both for determining marine growth (Gass & Roberts 2006, van der Stap et al. 2016, Thomson et al. 2018) and fish populations on and around offshore platforms (Pradella et al. 2014, McLean et al. 2018b) and pipelines (McLean et al. 2017, Bond et al. 2018a). Nevertheless, the usefulness of video archives collected by oil and gas companies should be systematically evaluated with respect to the general application of such footage in time and space.

Unlike in the GOM and California coasts, Australian oil and gas structures have been the subject of comparatively few studies with respect to the extent to which fish populations associate with them. The North West Shelf (NWS) of Western Australia is Australia's largest offshore oil and gas precinct, contributing around 70% of Australia's total crude oil and condensate production (Department of Industry Innovation and Science 2017). Offshore oil and gas production in Australia is relatively 'young' in comparison to that in the northern hemisphere, and as a result the economic and environmental factors associated with decommissioning have not yet faced the same level of scrutiny. However, offshore oil production has been declining as mature fields reach exhaustion and it is estimated that Australia's future decommissioning liability will reach US $21 billion over the next 50 years (National Energy Resources Australia 2016). The current provisions for decommissioning rigs in Australian waters stipulate complete removal of all supporting structures (National Offshore Petroleum Safety and Environmental Management Authority 2017). Policy on *in situ* decommissioning is currently under consideration in Australia (Techera & Chandler 2015), however the paucity of knowledge on platform ecology specific to the region has limited progression. Given the scale of decommissioning required on the NWS in the coming decades, understanding the ecological role of offshore platforms is necessary to best inform future decommissioning policy. In particular, understanding the vertical ecology of standing platforms is of critical importance given that RTR methods include options that eliminate shallow water habitats either through direct removal (topping) or through toppling.

This study was comprised of two key elements: (1) an evaluation of the utility of industry collected ROV video to ecological studies, and (2) the determination of how taxonomic richness, abundance, biomass and assemblage structure of fish populations vary with depth and structural complexity on two oil platforms. The platforms are situated on Australia's NWS in 54 m of water. A stringent scoring system is used to determine the ecological value of industry ROV video and recommendations are made to improve future video collection methods. The effect of depth and structural complexity on fish populations associated with platforms on the NWS is assessed using industry-derived vertical ROV video transects. The information will be of benefit to decisionmakers regarding the best-practice for decommissioning in this region. Furthermore, understanding the utility of ROV footage for ecological studies will allow data-mining of this valuable resource and improve future data collection.

2.0 Methods

2.1 Site Description

The platforms for this study operate within the Wandoo oilfield, located on the NWS approximately 75 km north-west of Dampier, Western Australia (Figure 1). Mean water depth in the Wandoo oilfield is 54 m and the surrounding benthic environment is comprised of predominantly soft sand and clay sediments (Fowler & Booth 2012, McLean et al. 2017). Production is via two separate platforms, Wandoo A and Wandoo B, located 1.7 km apart (Figure 2). Wandoo A was installed in 1993 and is an unmanned monopod wellhead platform with a single shaft 2.5 m in diameter, supporting a helideck and five production wells. The Wandoo B processing facility was installed in 1997 and consists of four shafts supported on a concrete gravity structure (CGS). The CGS is comprised of a rectangular base caisson that rises 17 m from the seafloor and is 114 m x 69 m in length and width. Each of the four shafts is 11 m in diameter and extends 69 m above the caisson roof. Oil produced from Wandoo A is piped to the CGS storage facilities supporting Wandoo B, then offloaded via a flexible pipeline to a CALM Buoy 1.2 km north of Wandoo B. Oil is transferred to export tankers via a floating hose connected to the CALM Buoy rather than making contact with the platforms. Following national regulations, a 500 m vessel exclusion zone surrounds all structures (Kashubsky & Morrison 2013).

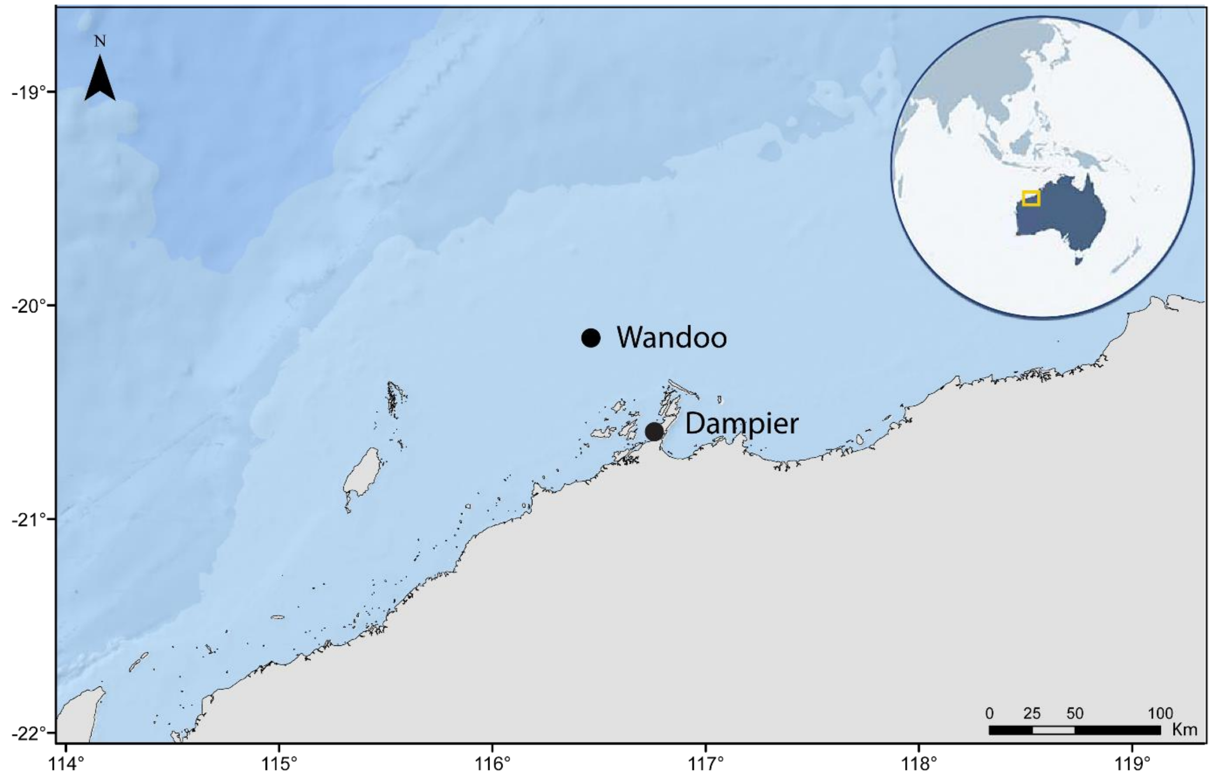

Figure 1. Location of the Wandoo Oilfield on the North West Shelf of Western Australia.

2.2 ROV Video Selection and Utility

The ROVs used during full-field surveys were predominantly work class, being tethered to the platform or vessel above via an umbilical connection cable, and comprised of a single camera and numerous attachments for cleaning, conductivity and inspection purposes. The ROV video interface includes the date and time of recording, information on orientation, pitch and roll of the ROV and a live depth reading in metres to one decimal place. Some early archives also included a descriptive voice-over from the ROV pilot on the procedures being conducted, as well as a printed description of the structure in view on the screen. A 50 mm dual-beam laser scale was present in some videos for measurement purposes, however it was intermittently used and rarely in contact with passing fish. The method of video collection varied significantly depending on the task or purpose of the ROV survey.

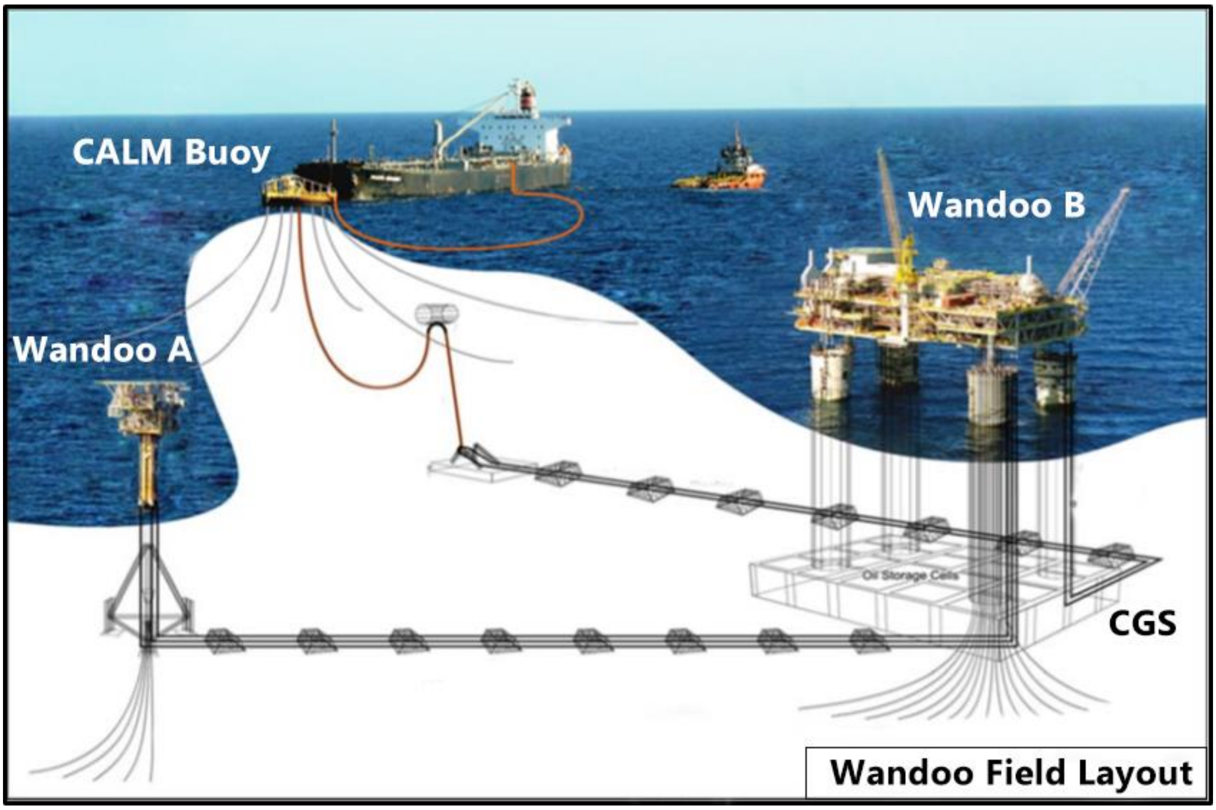

Figure 2. Wandoo oilfield schematic adapted from Vermillion Energy (2019). Wandoo A is a single shaft monopod and Wandoo B is a four-shaft facility supported on a concrete gravity structure (CGS). Oil is offloaded from Wandoo B to export tankers via the CALM Buoy. Not to scale.

ROV video from routine surveys conducted in 2007, 2008, 2011 and 2015 was available for analysis from Vermillion Oil and Gas Australia (Table 1). Surveys varied within each year depending on the task, ranging from cleaning protocols and conductivity assessments to targeted structural inspections and general environmental surveys. A total of 1521.16 gigabytes (GB) of video targeting structures on Wandoo A and Wandoo B was provided, excluding all surveys of the CGS walls, caisson roof and CALM Buoy (Table 1). A stringent scoring system was adapted from Pradella et al. (2014) to standardise the evaluation of the non-scientifically collected video. Videos deemed useful for analysis must (1) follow the shaft or structure of interest in a distinct vertical transect, either descending or ascending, (2) have ≥ 5 m visibility, (3) be slow moving to allow identification of fish species at each depth frame with no speed-blur and (4) have the shaft/structure take up between 60-80% of the field of view (FOV). Gass & Roberts (2006) noted differences in ROV footage that was collected in a spiralling fashion down the shafts to those that were surveyed on only one side, thus all video transects must maintain a consistent orientation and not vary from that original orientation more than 90° either side. Although each individual transect followed a consistent orientation, not all transects were oriented in the same direction due to large variability in the video collection methods. All footage should also be collected during daylight hours to limit diurnal influences on fish assemblages (Bond et al. 2018a).

The utility of industry collected ROV video for scientific purposes was assessed by comparing the amount of video received in GB to the amount deemed as usable for analysis following the scoring system. For each year that ROV surveys occurred, videos were classified as (1) targeted protocols (‘Protocols’), which are videos of targeted industry protocols that do not follow any standardised transect, such as cleaning and conductivity assessments, (2) distinct transects (‘Transect’), which are videos following platform shafts in a standardised transect, but are not usable due to violating one or more of the requirements of the scoring system, and (3) usable videos (‘Usable’), which are standardised transects that were usable for this study. The amount of video (in GB) of each category of ROV video (Protocols, Transects, Usable) was expressed as a percentage of the total amount of video received for that year. The time taken to analyse the ROV video archives was also calculated, from the data mining stage to the video analysis stage. The subset of usable videos was used to assess fish populations associating with the Wandoo platforms and recommendations are made on how to improve future ROV campaigns to align with scientific practices and enhance the value of industry ROV for ecological studies.

Table 1. The years of ROV surveys relevant to structures at Wandoo A and Wandoo B, with the month the survey took place and the amount of ROV video received in gigabytes (GB) from each year.

	Wandoo A		**Wandoo B**		
Year	**Month**	**Recieved (GB)**	**Month**	**Received (GB)**	**Total**
2007	October/November	16.43	November	15.02	31.45
2008	December	7.52	December	0.95	8.47
2011	April	10.80	April	15.20	26.00
2015	December	462.24	May	993.00	1455.24
Total		496.99		1024.17	1521.16

2.3 Vertical Distributions

Only videos from 2015 surveys were utilised in the assessment of vertical ecology. ROV video records from three separate shafts, Wandoo A (WNA), Wandoo B shaft 1 (WNB1) and Wandoo B shaft 3 (WNB3), were selected for analysis of fish populations based on the availability of relevant ROV video. All shafts had three replicate video transects available in the ROV archives. Vertical transects at WNA extended the full 54 m depth profile from surface to seafloor, whilst transects at WNB1 and WNB3 extended to 37 m from the surface to the CGS roof. The bottom 17 m that encompassed the outer portions of the CGS were excluded from analysis due to differences in structure.

Each transect was stratified into 10 m depth categories along the shaft (2-12 m, 12.1-22 m, 22.1-32 m, 32.1-42 m, 42.1-52 m) and sampled in a vertical video transect. Within each 10 m depth category, 20 individual frames at random depth points at which the video was paused was selected and formally analysed to identify fish species. Subsampling by frame reduced the risk of speed bias, whereby transects conducted at slower speeds may have a greater number of fish visible.

2.4 Video Analysis

All videos were converted to .mp4 format in the highest possible resolution (1920 x 1080 pixels and 24 frames per second) using Adobe Media Encoder (Adobe 2019). The fish assemblage was characterised by taxonomic richness, abundance and biomass. Using EventMeasure^{TM} (SeaGIS Pty Ltd 2017), fish were identified to the lowest taxonomic level possible. Where individuals could not reliably be identified to species they were identified to genus or family. When clear morphological differences were present between adults and juveniles, individuals were appropriately classified to life history stage. Abundance was estimated for each taxon as the number observed in the frame.

Habitat was characterised by the structural complexity of hard substrate provided by the platform shafts. Access ladders, production pipelines, export risers, firewater pumps, conductors and substructure base supports were present across all three shafts and added varying degrees of structural complexity at different depths. A categorical scale of increasing structural complexity was established, ranging from 0 being the least complex to 3 being the most complex. The scale included: 0 = bare shaft with no parallel or horizontal support structures; 1 = bare shaft with a parallel riser, pipeline or conductor, but no horizontal supports in the field of view; 2 = shaft with a small-moderate sized refuge attached, such as a hollow flange or dished conductor guide, but no parallel structures; 3 = shaft with a parallel riser *and* horizontal support structure or small-moderate refuge. A complexity value was assigned to each frame.

2.5 Statistical Analysis

The data generated by EventMeasure ^{TM} were first cleaned in Microsoft Excel prior to statistical analysis to generate taxonomic identifications, abundance estimates, and values of depth and structural complexity for each frame. Mean values were calculated for taxonomic richness, abundance, depth and structural complexity for each 10 m depth category for each shaft.

Biomass was calculated separately as the single camera on the ROVs meant that stereo length measurements could not be taken and the laser was used infrequently. The common length for each species or genus as reported in FishBase (Froese & Pauly 2019) was thus used as a proxy for *in situ* lengths (Appendix 1). Common lengths for each family were calculated as 75% of the maximum length for the family listed in Kulbicki et al. (2005), as an assessment of the ratio of common length to total length indicates the ratio is typically ~75%. Taxa were then assigned a size category of large (>50 cm), medium (25-50 cm) and small (< 25 cm) (Appendix 1). To calculate biomass, individual fish weight (W) was then calculated as a function of common length (L), using the equation $W = aL^b$, where a is a parameter describing body shape and condition and b indicates allometric growth in body proportions. Values for a and b were also obtained from FishBase (Froese & Pauly 2019) using the rfishbase 3.0 package (Boettiger et al. 2012) in the R language for statistical computing (R Core Team 2015). For fish identified only to the family level, values for a and b were obtained from Kulbicki et al. (2005). Biomass estimates for each taxa were calculated by multiplying the individual weight estimates by the mean abundance for each 10 m depth category, rather than per frame to minimise the effect of double counting fish that may have moved between frames. Biomass was then averaged for each of the size classes for each 10 m depth category. Finally, depth categories were assigned to 'shallow' and 'deep' sections of the platforms relevant to the decommissioning scenarios of topping. In the US, reefed platforms must maintain a minimum of 26 m clearance to the surface for navigational safety (Bull & Love 2019). Therefore, we described 'shallow' as depth categories 1-2 (2-22 m) and 'deep' as depth categories 3-5 (22.1-52 m), the closest to a realistic proxy of topping, and averaged biomass estimates for each of these sections. The biomass of large, medium and small fish was tested between 'shallow' and 'deep' sections via an independent samples t-test assuming unequal variances.

All univariate analyses were conducted in the R language for statistical computing (R Core Team 2015) using the packages AER (Kleiber & Zeileis 2008), nlme (Pinheiro et al. 2019) and multcomp (Horthorn et al. 2008). Mean abundance values were log10 transformed to stabilise variance. Linear regression models predicting mean taxonomic richness and abundance included depth, structural complexity and dummy variables distinguishing different shafts, including all interactions, as predictor variables. Model reduction was conducted by first considering interactions between the dummy variable and either depth or structural complexity.

The interaction with the highest p-value greater than 0.05 was then removed and the model was rerun. Consideration was then given to the remaining interaction and the continuous variable associated with the removed interaction, with the term with the highest p-value great than 0.05 also removed. This process was repeated until only significant variables or variables associated with significant interactions were retained.

Taxonomic assemblage data were analysed using a distance-based linear model (DistLM; Anderson et al. 2008) with the same predictor variables as univariate analyses in the PRIMER v6 statistical software package (Clarke & Gorley 2006) using the PERMANOVA + add-on (Anderson et al. 2008). Assemblage data were first square root transformed and analysed using Bray-Curtis dissimilarities. The most parsimonious model was selected using the same model reduction method described for richness and abundance. A distance-based redundancy analysis (dbRDA) plot was used to construct a constrained ordination of the assemblage data. Species vectors were overlayed on the dbRDA plots with a Pearson's correlation of 0.4.

3.0 Results

3.1 ROV Utility

Only 4.9% (75.25 GB) of the total 1521.16 GB of video considered relevant to the analysis of vertical distributions of fish was usable for analysis. All the usable video was from the high definition 2015 ROV surveys (Table 2). Targeted protocols that did not follow a defined vertical transect, such as cleaning, conductivity assessments and structural inspections, comprised 83.8% (1274.9 GB) of all available footage (Figure 3). All video from ROV surveys in 2008 and 2011 were classified as targeted protocols, as no videos followed a distinct transect. Videos that followed a defined vertical transect but were unusable comprised 11.2% (171 GB) (Figure 3). The majority of ROV videos that were assessed as not usable for analysis were those that did not follow a distinct vertical transect (Figure 4). Of those that did follow a vertical transect, very few were not usable due to visibility being <5 m (2 GB). Speed of the transect, however, was an issue in some videos, with the ROV travelling too fast or erratically (side-to-side motion) thereby creating blurry imagery (75 GB). The FOV requirement of video also limited the use of video transects (19 GB), with some being too far or too close to the shaft (Figure 4).

Table 2. The amount of relevant industry ROV video received and the amount of ROV video deemed usable for this ecological study. All values are in gigabytes.

	Wandoo A		Wandoo B	
Year	**Recieved**	**Used**	**Received**	**Used**
2007	16.43	-	15.02	-
2008	7.52	-	0.95	-
2011	10.80	-	15.20	-
2015	462.24	37.41	993.00	37.84

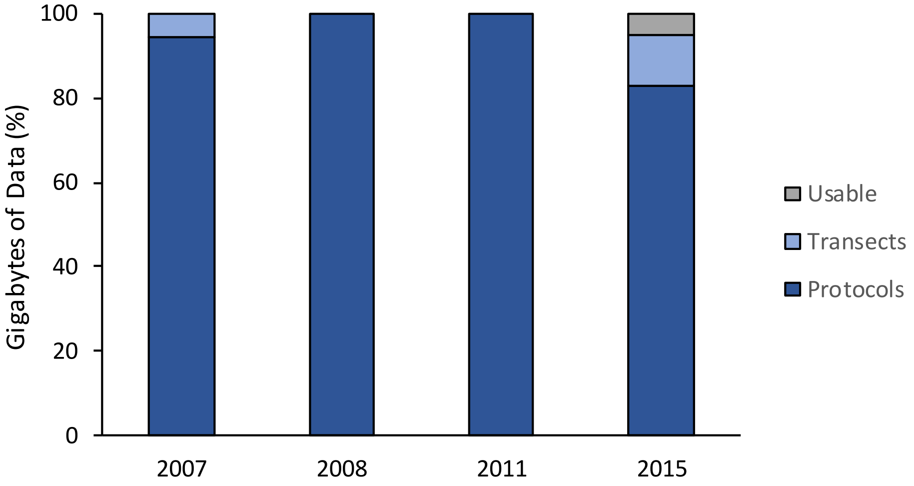

Figure 3. The gigabytes of data received, expressed as a percentage of the total amount for that year, that represented standard industry protocols ('Protocols'), such as cleaning, conductivity, inspection surveys, compared to videos that followed a defined transect but were not usable ('Transects') and video transects that were usable ('Usable').

The time spent identifying usable footage and analysing the individual transects was considerable, totalling 720 hours or 102 days. The data mining process alone, including the identification and extraction of usable video transects, required 248 hours (31 days) of work. The video analysis process required a total of 472 working hours (59 days), including video conversion, species identification and identification checks.

The primary reasons for the small proportion of video deemed usable for analysis was the low resolution of video pre-2015 and the haphazard sampling method of video collection. Early ROV video archives exhibited low resolution, usually 720 x 576 pixels, overexposure in sunlit regions, underexposure in shaded regions and high contrasts, a combination of which often limited visibility. The method of ROV video collection across all years was variable due to the primary purpose being standard industry operations, with the majority of videos (83.8%) being industry protocols that did not follow the platform shafts in a distinct vertical transect.

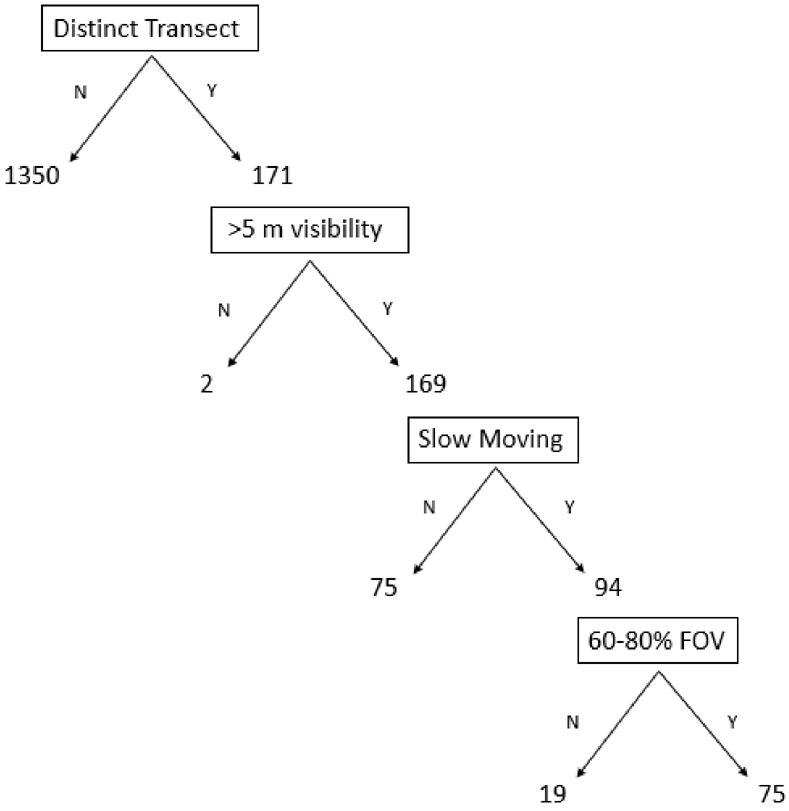

Figure 4. Flow chart of the amount of ROV video (in gigabytes) that was deemed usable/unusable (Y/N) at each stage of the video scoring system. FOV = Field of view.

3.2 Taxonomic Richness and Abundance

A total of 111 taxa of fish from 25 families were recorded from vertical ROV transects across all shafts in 2015. Unidentified clear larvae were also recorded at WNA. The most commonly observed species across all shafts and depths were unidentified herring (Clupeidae spp.) and damselfish (Pomacentridae spp.), comprising 39.7% and 28% of all individuals respectively. Herring scad (*Alepes vari*; 5.6%), luminous cardinalfish (*Rhabdamia gracilis*; 5.3%), regal demoiselle (*Neopomacentrus cyanomos*; 3.8%), ninespine batfish (*Zabidius novemaculeatus*; 3%) and threespot humbugs (*Dascyllus trimaculatus*; 2.6%) were also commonly seen on all transects.

Mean species richness per frame was highest at both WNB1 (6.66 ± 0.52 SE) and WNA (6.41 ± 0.52 SE) respectively, whilst WNB3 had significantly fewer species identified per frame (2.59

± 0.3 SE; Figure 5). Clear differences in mean fish abundance were observed between shafts, with WNA having the highest abundance per frame (320.11 ± 86.73 SE), followed by WNB1 (68.31 ± 10.23 SE) and WNB3 (19.18 ± 4.69 SE; Figure 5).

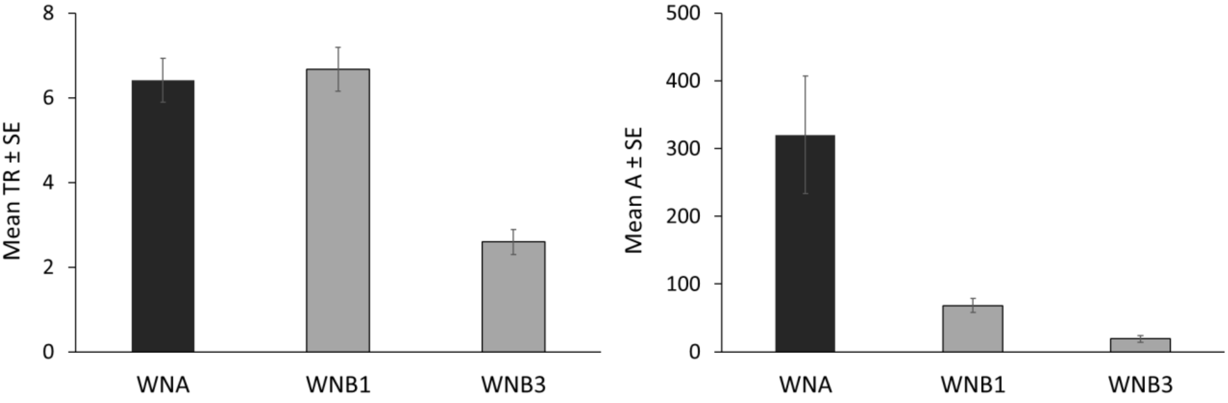

Figure 5. Mean taxonomic richness (Mean TR) and abundance (Mean A) across shafts WNA, WNB1 and WNB3. Error bars denote standard error.

Over 80% of variation in the observed mean taxonomic richness values was explained by the regression model. Mean taxonomic richness was greatest at shallow portions of all platforms and declined significantly with depth ($P < 0.001$). However, the rate of this decline was dependent on the shaft and the level of structural complexity (Table 3, Figure 6). The significantly lower number of taxa at WNB3 reflected the lack of structural complexity on the shaft when compared to WNA and WNB1. The rate of decline in the number of taxa present was greatest at WNA and lowest at WNB3 (Figure 6)

The regression model explained 76.7% of variation in observed mean abundance values. Changes in depth and different shafts significantly affected the abundance of fish, however complexity did not (Table 3). This is likely due to a high number of pelagic species being visible behind the shafts, particularly at WNA, which did not appear to be influenced by small-scale structural complexity. The rate and direction of change in abundance with depth varied considerably between shafts (Table 3). Both WNA and WNB3 demonstrated clear declines in abundance with depth until ~40 m, although there is a considerable spike in abundance at deep sections of WNA (Figure 6). This late spike is attributed to the high numbers of unidentified herring at depths below 42 m that were observed in all replicate transects. Fish abundance at WNB1 followed a different trajectory, increasing slightly with depth until 26 m, then declining until the base of the shaft at 37 m.

Table 3. Regression results based on the most parsimonious model predicting taxonomic richness and abundance. DVA is the dummy variable distinguishing WNA from WNB1 and WNB3; DVB1 is the dummy variable distinguishing WNB1 from WNA and WNB3.

	Coefficients	Std. Error	t-statistic	P-value
Taxonomic Richness				
Intercept	3.521	0.644	5.466	<0.001
Mean Complexity	0.913	0.398	2.297	0.028
Mean Depth	-0.075	0.019	-3.880	<0.001
DVA	3.417	0.683	5.005	<0.001
DVB1	2.893	0.795	3.638	0.001
Abundance				
Intercept	1.519	0.239	6.367	<0.001
Mean Depth	-0.030	0.011	-2.773	0.009
DVA	0.725	0.306	2.368	0.024
DVB1	0.077	0.338	0.228	0.821
DVA x Depth	0.030	0.012	2.374	0.024
DVB1 x Depth	0.035	0.015	2.398	0.023

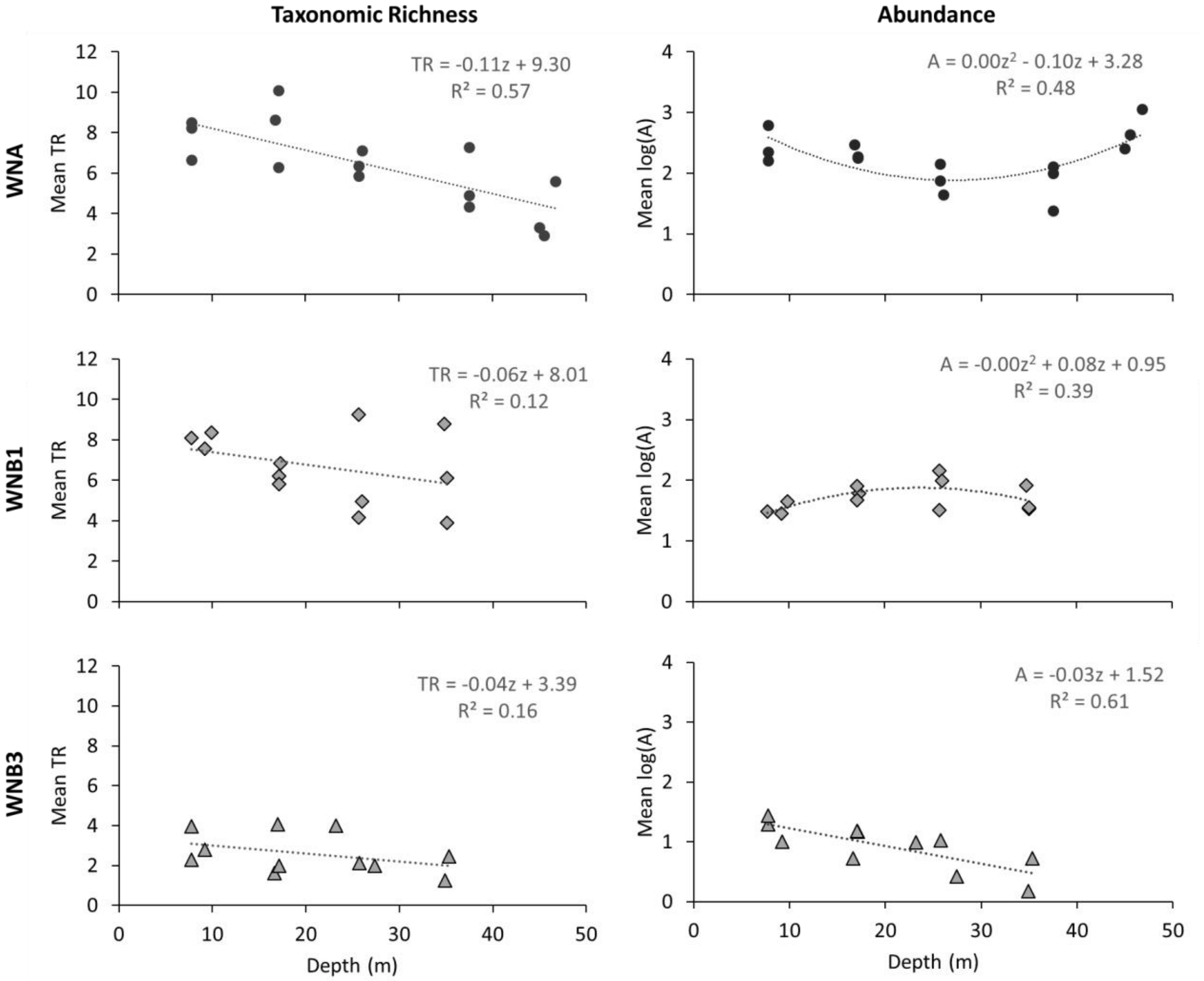

Figure 6. Trends in mean taxonomic richness (TR) and abundance (A) with depth (z) across shafts. Wandoo A = WNA, Wandoo B shaft 1 = WNB1 and Wandoo B shaft 3 = WNB3.

When comparing the number of taxa occurring at ‘shallow’ (2-22 m) and ‘deep’ (22.1-52 m) depths, 27 taxa (24.3% of total taxa) only occur in depths above 22 m (i.e. restricted to ‘shallow’), whilst 21 taxa (18.9%) only occur in depths below 22 m (i.e. restricted to ‘deep’). The remaining 63 taxa (56.7%) occur over a mixed depth range. Furthermore, the number of taxa only occurring at depths above 32 m, slightly deeper than what would be removed via topping, is 50 (45% of the total taxa). At ‘shallow’ portions of the platform (<22 m), unidentified damselfish were the most abundant taxa by a considerable amount (45.6% of all fish). Herring (13.8%), herring scad (9.8%), threespot humbugs (5.8%), ninespine batfish (4.6%) and regal demoiselle (4.3%) were also common. Deeper sections (>22 m) were overwhelmingly dominated by unidentified herring, comprising over 60% of all individuals. Unidentified damselfish (14.2%) and luminous cardinalfish (9.6%) were also abundant, followed by regal demoiselle, herring scad, golden trevally (*Gnathanodon speciosus*), rankin cod (*Epinephelus multinotatus*) and yellowspotted trevally (*Carangoides fulvoguttatus*).

3.3 Distribution of Biomass

No statistical difference (P<0.05) in mean biomass was detected between each size class at ‘shallow’ (2-22 m) and ‘deep’ (22.1-52 m) depths, possibly due to low power associated with the small sample size (N=6; shallow/deep per WNA, WNB1, WNB3), however trends are in the expected direction (Figure 7). Mean biomass of large fish at ‘shallow’ depths (20.16 kg ± 9.69 SE) was lower than those at ‘deep’ depths (53.42 kg ± 29.1 SE). The comparatively lower biomass of large fish in ‘shallow’ portions of the platform results in a moderate biomass of medium fish and small fish respectively. Conversely, the high biomass of large fish at depths >22 m results in a trophic cascade with medium fish having a low biomass (3.89 kg ± 1.84 SE) allowing for a higher biomass of small fish (16.53 kg ± 15.22 SE). Much of the biomass of small fish in ‘deep’ sections can be attributed to the abundance of unidentified herring observed at the base of all shafts.

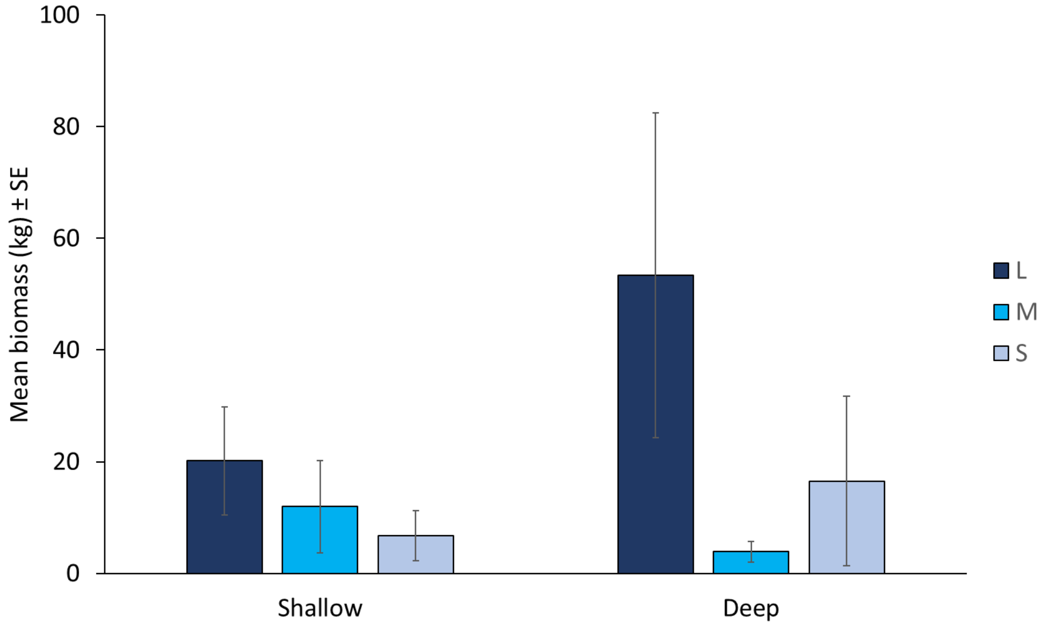

Figure 7. Distribution of biomass, in kg, averaged across all shafts for large (L), medium (M) and small (S) fish at shallow (2-22 m) and deep (22.1-52 m) depths. Biomass estimates are derived from species common lengths.

3.4 Taxonomic Composition

Over 52% of the variation in fish assemblage is explained by the most parsimonious DistLM model (Table 4). Both depth and structural complexity had significant effects ($p < 0.01$) on the taxa present, however the effect depends on the shaft. Differences between shafts explained the greatest proportion of difference in assemblage structure, particularly between WNA and both Wandoo B shafts (15.4% of explained variation; Table 4). This effect is visible in the dbRDA ordination (Figure 8), whereby distinct spatial separation between shafts on WNA and Wandoo B are present. Depth and complexity were not correlated ($r^2 = -0.05$).

Table 4. DistLM results based on the most parsimonious model predicting species assemblage structure. DVA is the dummy variable distinguishing WNA from WNB1 and WNB3; DVB1 is the dummy variable distinguishing WNB1 from WNA and WNB3.

	SS	Psuedo-F	P	Cum. Prop.	Residual df
Complexity	10329	3.617	0.001	0.091	36
Depth	12886	5.016	0.001	0.205	35
DVA	17467	8.196	0.001	0.361	34
DVB1	5676.7	2.805	0.001	0.411	33
DVA x Complexity	4010.7	2.045	0.008	0.445	32
DVA x Depth	4843.2	2.592	0.002	0.488	31
DVB1 x Depth	4285.2	2.397	0.007	0.526	30

The first axis, dbRDA1, explains differences between shafts, whilst depth increases with positive values of dbRDA2 and complexity increases with negative values of dbRDA2 (Figure 8). WNA is characterised by a mix of larger mobile taxa and smaller reef-dependent fish, both of which are affected by depth and structural complexity. Smaller-bodied fish, such as the threespot humbug and bluehead wrasse (*Thalassoma amblycephalum*), were highly associated with shallower and more structurally complex habitats on WNA (Figure 8). In contrast, larger fish like giant trevally (*Caranx ignoblis*) and crimson snapper (*Lutjanus erythropterus*) were more common in moderate-deep and more open habitats. Significant numbers of highly mobile unidentified herring were also present at deeper sections of WNA.

The taxa associated with shafts on Wandoo B were predominantly reef-associated fish of varying size (Figure 8). Species ranged from smaller reef fish such as the regal demoiselle and blue-streak cleaner wrasse (*Labroides dimidiatus*) to larger predatory species such as the frostback rockcod (*Epinephelus bilobatus*). WNB3 had very low taxonomic richness and abundance and hence most fish associations were with WNB1. A tawny nurse shark (*Nebrius ferrugineus*), the largest species observed across all transects, was identified at WNB1 resting on a horizontal riser support beam at 14.7 m.

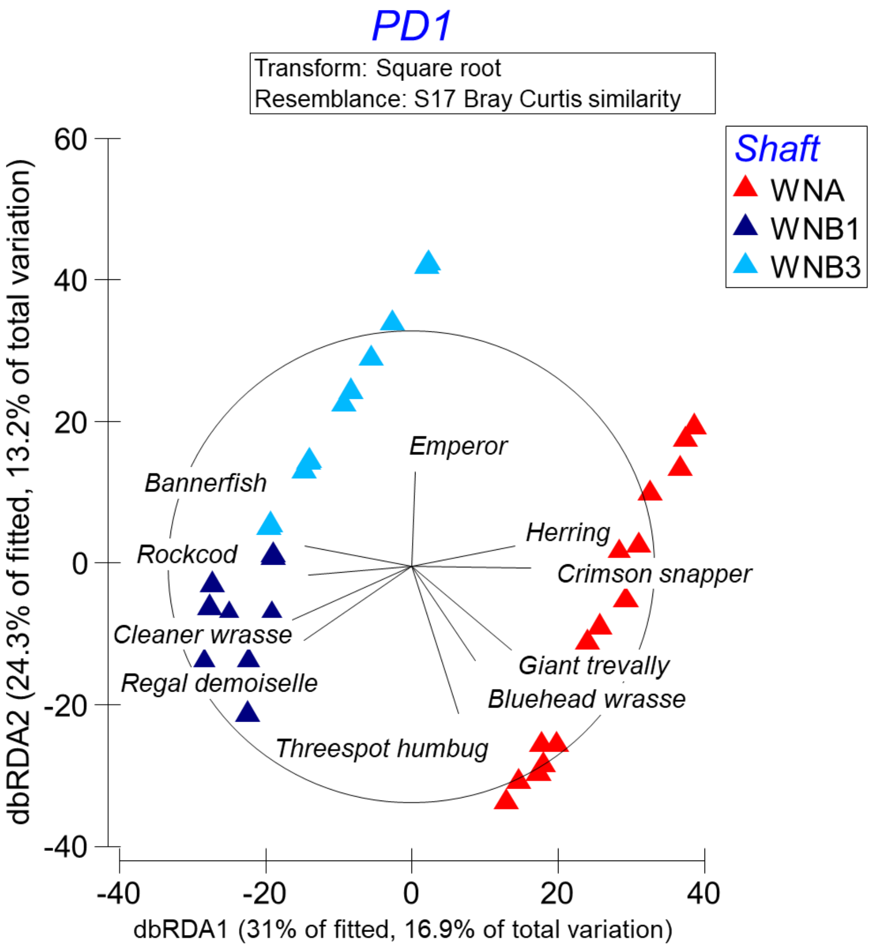

Figure 8. Distance-based redundancy analysis (dbRDA) ordination of the most parsimonious distance based linear model (DistLM) predicting fish assemblage structure by shaft. Vectors are based on a Pearson's correlation of R = 0.4. Emperor = Lethrinidae sp.; herring = Clupeidae spp.; crimson snapper = *L. erythropterus*; giant trevally = *C. ignobilis*; bluehead wrasse = *T. amblycephalum*; threespot humbug = *D. trimaculatus*; regal demoiselle = *N. cyanomos*; cleaner wrasse = *L. dimidiatus*; rockcod = *E. bilobatus*; bannerfish = *Heniochus* sp.

Clear distinctions in assemblage structure with depth across all shafts are visible when the dbRDA is ordinated by depth category (Figure 9). Reef-associated damselfish (*D. trimaculatus*, *Pomacentrus coelestis*), wrasse (*Thalassoma* sp.) and parrotfish (*Chlororus* sp.) species were characteristic of shallower portions of the platforms between zero and 22 m. Larger predatory species such as yellowstreaked snapper (*Lutjanus lemniscatus*), rankin cod and grouper (*Epinephelus* sp.) were highly associated with deeper sections of platforms below 32 m. The red-belted anthias (*Pseudanthias rubrizonatus*) and unidentified herring were also common at depths below 32 m.

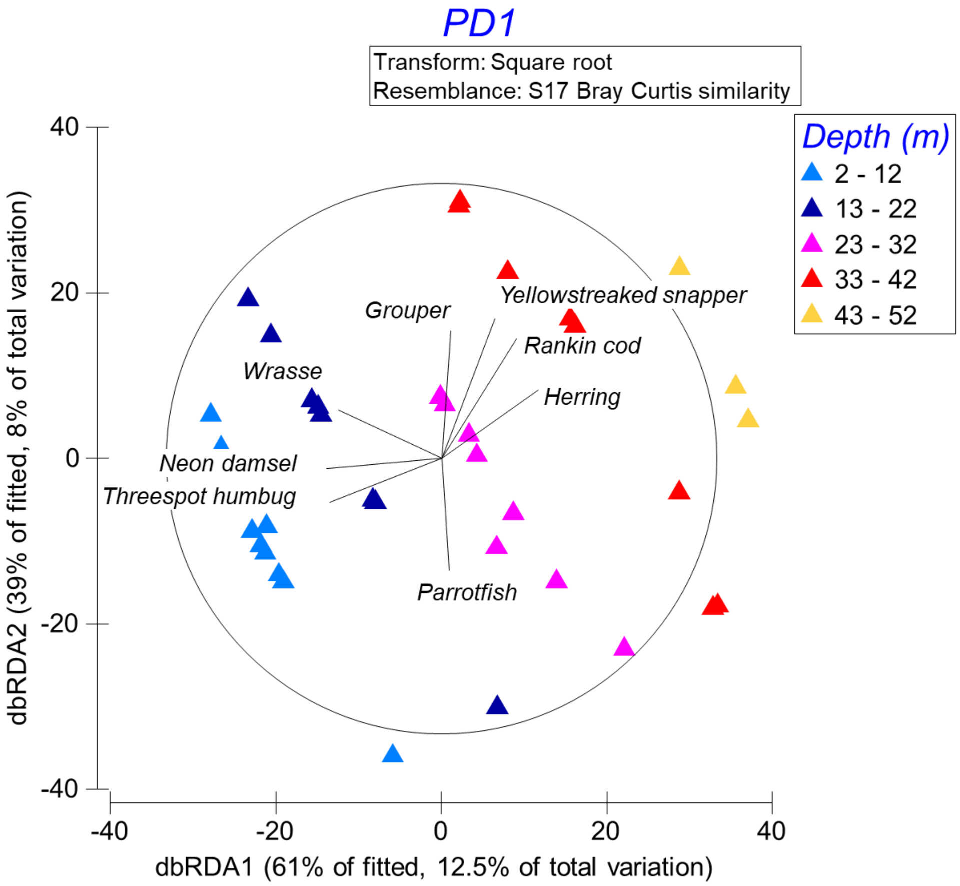

Figure 9. Distance-based redundancy analysis (dbRDA) ordination of assemblage data by depth categories. Vectors are based on a Pearson's correlation of R = 0.4. Grouper = *Epinephelus sp.*; yellowstreaked snapper = *L.* lemniscatus; rankin cod = *E. multinotatus*; herring = Clupeidae sp.; parrotfish = *Chlororus sp.*; threespot humbug = *D. trimaculatus*; neon damsel = *P. coelestis*; wrasse = *Thalassoma sp.*

A number of additional species were observed interacting with the structure but were not included during analysis. These species were often identified between two frames that were not at the required depth or during a period where the ROV veered from the standardised transect and therefore had to be excluded following the video scoring system. The species observed included multiple stripey snapper (*Lutjanus carponotatus*) at the base of all shafts, a Queensland groper (*Epinephelus lanceolatus*) at 49 m at WNA, two individual blotched fantail rays (*Taeniurops meyeni*) on the CGS roof at WNB1, single carcharhinid sharks (*Carcharhinus* sp.) at 13 m at WNB1 and 34 m at WNB3, and two blacktip reef sharks (*Carcharinus melanopterus*) at 30 m at WNA. Many other fish, particularly cryptic species in close association with the structures and larger pelagic species that associate with the structure more loosely, were likely missed due to the method of video analysis.

3.5 Juveniles

Four species of juvenile fish were identified based on morphological differences. The four juvenile fish species were the threespot humbug, bluehead wrasse, unidentified clear juveniles and semicircle angelfish (*Pomacanthus semicirculatus*), with the semicircle angelfish being the only juvenile observed on Wandoo B structures (WNB1). The threespot humbug was the most frequently observed juvenile (74.1% of juvenile observations) and occurred between 10.1-22 m depth, with a mean depth of 14.9 m. All threespot humbug juveniles were seen in groups of at least two and up to 16 individual juveniles in one frame, often mixed with adults of the same species. The bluehead wrasse was the second most frequently seen juvenile (11.1% of juvenile observations) and was observed between 13.2-14.6 m. The single semicircle angelfish was observed at 34.1 m depth. A clear, unidentifiable larval-like juvenile (Juvenile spp.) was the fourth species and was observed at depths between 37.9-39.1 m on WNA. Almost all identified juveniles were associated with structurally complex portions of the platform (complexity category 2 and 3), with a mean complexity value of 2.26 for all juveniles.

Separate to the formal analysis, a juvenile red bass (*Lutjanus bohar*) was observed at 15 m depth on WNB1 between two depth frames and was therefore not included in the results. However, its presence does add information on the distribution of juvenile fish. Juvenile red bass, often mimicking Pomacentrids in the *Chromis* genus, was seen in close association with several West Australian puller (*Chromis westaustralis*), smoky puller (*Chromis fumea*), regal demoiselle, threespot humbug and a single tawny nurse shark. The structural complexity of the shaft where the juvenile red bass was observed was category 3.

4.0 Discussion

This study represents an in-depth assessment of the utility of industry collected ROV video for ecological studies and, using a subset of usable ROV videos, insights into the vertical distributions of fish on the Wandoo platforms on the NWS were gained. Much of the ROV video provided had limited use for scientific studies and a number of recommendations are put forth on how to improve future ROV surveys to align with standard scientific practices. Furthermore, assessment of existing ROV video determined that depth and structural complexity significantly affect attributes of the fish assemblage on the Wandoo platforms and highlights the potential role of the midwater habitat as a juvenile nursery similar to those observed on offshore platforms in the GOM and California coast.

4.1 ROV Recommendations

The ROV video archives made available were limited in use for scientific purposes. Only a fraction (4.9%) of the total amount available was able to be utilised for this study, all from the high definition imagery in 2015. The single largest factor inhibiting use of industry collected ROV video for scientific purposes is the haphazard sampling method (83.8% of video received), with the video being primarily collected for industry use, not science. Video quality also hampered scientific utility, with surveys conducted pre-2015 exhibiting low resolution, overexposure in sunlit areas, underexposure in shaded areas and high contrasts. Nevertheless, the ROV footage provides insight into the number and types of fish species interacting with offshore platforms, and with thorough assessment of the archives some standardised studies can be conducted.

Significant improvements can be made to ROV data collection methods so their scientific value is increased. Industry-science collaborations are an effective route to increasing the scientific value of footage (McLean et al. 2018a). For these collaborations to be effective, however, ROV pilots and operators must be informed on the scientific requirements for statistical analysis. Scientists are rarely present during ROV surveys and hence guidelines, training programs and instructional videos that inform pilots on the scientific practice is necessary. The SERPENT (Scientific and Environmental ROV Partnership using Existing Industrial Technology) project, which has a long history of scientific partnership with industry operators in the GOM, already has an instructional video on how ROV pilots can conduct simple standardised surveys (http://bit.ly/2yrpa48), however there is significant room for improvement. Greater collaboration in this area will also ensure a win-win approach whereby the scientific requirements neither interfere nor substantially add to the cost of ROV campaigns.

Several recommendations for future ROV campaigns, based on the observations of the historical data provided by Vermillion Oil and Gas and the information on the SERPENT project, have been collated to improve the utility of this resource for future research.

- *Video Quality*: All video should be recorded in high definition video only (minimum 1920 x 1080 pixels and 25 frames per second). Low intensity white lights should be used in all surveys to improve colouration of organisms and enhance identification capabilities in low-light environments. Although artificial light can affect fish behaviour in variable ways (Fitzpatrick et al. 2013), all surveys will be consistent if lighting is used throughout.

- *Speed*: All ROV transects should travel at a consistent speed to eliminate speed bias. Based on the footage used in this study, transects should not descend/ascend at speeds greater than 0.5 m/s, as this was the fastest the ROV could move before identification of species became difficult. Conducting a single vertical transect at this speed in 50 m of water (comparable to Wandoo A) would take 100 seconds (1.6 minutes) to complete.
- *Vertical transects*: Two distinct vertical transects of the complete depth profile should be completed on each shaft; one descending at 5 m from the main shaft for observation of larger demersal and pelagic species that interact with the structure more loosely, and one ascending back to the surface at 1 m from the main shaft for observation of smaller cryptic species. This should be completed on the north and south sides of each shaft, equating to four transects per shaft: two on the north face and two on the south face. Orientation and speed should remain constant.
- *Horizontal transects*: Horizontal transects can be conducted to examine the biological footprint of the platforms. At shallow platforms (<70 m), two horizontal transects (outbound and inbound) should occur in each direction (N, E, S, W), totalling eight transects. These transects should be replicated at two depths: one at 10 m below the surface and one along the seafloor. This allows for some comparison to baited remote underwater video systems (BRUVS) deployed at mid-water column (10 m; Letessier et al. 2013, Bouchet & Meeuwig 2015) and seabed (Cappo et al. 2006, Harvey et al. 2012b) depths. At deeper platforms, horizontal transects should be sampled at 10 m below surface and on the seabed, with additional water column transects stratified by depth. Depending on the length of spool on the umbilical connection to the platform above, transects should aim to extend 150 m out from the structure. In cases where the ROV is deployed from a vessel, rather than the platform, transects can extend 500 m, allowing for complete coverage of the 500 m exclusion zone that surrounds all oil and gas structures (Kashubsky & Morrison 2013). The use of bottom thrusters should be limited during seabed transects to limit sediment disturbance. Orientation and speed should remain constant.
- *CGS Surveys*: Rectangular CGS base structures that support larger facilities, such as Wandoo B, should also be surveyed where possible as they are likely to be left in place if *in situ* decommissioning occurs. Transects should be conducted along the two longest parallel edges of the CGS and, depending on the size of the CGS, additional transects

separated by 15 m traversing the top side of the CGS. Orientation and speed should remain constant.

- *Stereo-video*: If possible, the addition of high definition stereo-video cameras attached to ROV's during transects would allow for accurate measurement of fish, estimates of biomass and 3D modelling of fish density. Although unlikely to be used during standard industry operations, if adequate industry-science partnerships can be formed and the addition of stereo-video cameras can be used then the value of this resource would increase significantly. In the absence of stereo-video cameras, the standard dual-beam lasers attached to ROVs should be used to provide some measure of distance from shaft and lengths of fish in contact with the lasers.

4.2 Vertical distribution of fishes

Trends in taxonomic richness on both Wandoo A and Wandoo B were clear. The number of taxa present was highest in the shallow midwater sections of all three shafts and significantly declined with depth. Furthermore, over 45% of all taxa observed occurred only at depths shallower than 32 m. Changes in abundance were less distinct, however both WNA and WNB3 demonstrated significant declines in abundance with depth to 40 m. Similar trends have been observed in natural coral reef systems (Brokovich et al. 2008) and on oil pipelines on the NWS covering broad depth profiles (Bond et al. 2018b), whereby mean species richness and relative abundance of fish decrease with depth. These findings contrast, however, with those in Thomson et al. (2018), whereby fish densities were significantly lower between 10-25 m than 25-50 m on an oil platform on the NWS. Platforms in southern California generally exhibit lowest fish densities in shallow portions of platforms (0-30 m) and increase significantly with depth (Love & Nishimoto 2012, Claisse et al. 2015), however this is due to assemblages being overwhelmingly dominated by deeper-dwelling rockfish (*Sebastes* spp.) (Love et al. 2006, 2009, 2012). It appears that the trends in richness and abundance at the Wandoo platforms reflect what is commonly seen in natural reef systems but not on existing oil and gas platforms. The vertical relief provided by both Wandoo platforms is therefore a crucial component in determining the ecological value of the standing platform.

The composition of taxa changed significantly along the vertical depth gradient on each shaft. The shallow portion of each platform was generally dominated by smaller reef-associated fish, such as damselfish (e.g. threespot humbug, neon damselfish) and wrasse (e.g. bluehead wrasse), whilst larger predatory fish like grouper (e.g. rankin cod) and snapper (e.g. yellowstreaked snapper, crimson snapper) were typically associated with structures at depths below 32 m. Large numbers of unidentified herring were also present in association with structure below 42 m, particularly at WNA. Trends in the vertical distribution of biomass highlight this vertical gradient, with a high biomass of large fish (>50 cm) being present at depths below 22, whilst the biomass of medium (25-50 cm) and small (<25 cm) fish combined was comparatively higher at depths above 22 m. The taxonomic composition on both Wandoo platforms varies considerably from that found on oil infrastructure in other parts of the NWS. The assemblage on oil pipelines on the NWS, as would be expected due to their presence on the seabed, lacks in shallower reef-associated fish and comprises primarily of demersal species such as threadfin bream (*Nemipterus* sp.), snapper (*Lutjanus* sp.), cod (*Cephalopholis* sp.) and grouper (*Epinephelus* sp.) (McLean et al. 2017, Bond et al. 2018a,b,c). Even a pipeline on the NWS present at depths as shallow as 9 m demonstrates a different taxonomic composition (Bond et al. 2018b). The composition of species on the Goodwyn Alpha Production Platform on the NWS also differed to that at Wandoo (Thomson et al. 2018). It is therefore important to assess the composition of taxa associating with oil and gas platforms on a case by case basis, particularly in relation to decommissioning policy, as trends in one location, no matter how similar the ecological setting, may not be representative of other locations.

The structural complexity of the platforms had a significant effect on the attributes of the fish assemblage. A greater number of taxa, particularly of smaller reef fish, were present in structurally complex portions of the platform where both vertical and horizontal structures were present. This is expected as high diversity is often associated with marine habitats that provide high structural complexity of hard substrate (Friedlander & Parrish 1998, Bonaca & Lipej 2005, Wilson et al. 2012). The effect of complexity, however, is not limited to smaller-bodied fish. On WNA, for example, several deeper-dwelling species like brownbarred rockcod (*Cephalopholis boenak*), orange-spotted grouper (*Epinephelus coiodes*) and rankin cod were observed at depths up to 10 m perched on horizontal riser supports and conductor guides. Similar findings have been noted on Californian platforms, whereby structurally complex platforms harbour increased densities of rockfish at midwater depths than on less complex platforms (Love & Nishimoto 2012). Differences in structural complexity, and therefore richness and abundance, were particularly evident between WNA and both shafts at Wandoo B. This is primarily due to WNA being a single shaft monopod platform of only 2.5 m diameter with all supporting infrastructure (i.e. export risers, substructure base supports) following the main shaft from surface to seafloor, providing ample complexity of varying size for a range of species throughout the entire depth profile. The four shafts at Wandoo B are large in comparison to WNA, being 11 m in diameter. The large surface area provided by Wandoo B shafts can be less structurally complex than WNA, particularly when there is a lack of additional structure attached, inadvertently acting as a large ‘flat’ surface providing little refuge space for smaller cryptic species. WNB3 demonstrated very little structural complexity in most video transects and as a result demonstrated the lowest abundance and richness of all shafts across all depths.

The presence of juvenile fish observed between 10 and 22 m at WNA provides some evidence that the shallow midwater habitat of oil platforms may provide a nursery function for reef fishes. The number of juveniles identified is a conservative estimate, as individuals were only marked as juvenile when morphological differences between life stages were clear. It is likely that many juveniles, particularly those that do not display ontogenetic morphological changes, were marked as adults due to the absence of measurements. Nevertheless, it seems that reef-associated fish like threespot humbug and bluehead wrasse may be self-recruiting to the midwater sections of the platform rather than dispersing to other habitats. Self-recruitment of coral reef fishes has been shown to be relatively common, even for species with relatively long pelagic larval durations (Jones et al. 1999, 2005, Almany et al. 2007). Damselfish species in the *Dascyllus* and *Pomacentrus* genera can have up to 68% juveniles self-recruiting to their natal population (Jones et al. 1999, Bernardi et al. 2001, Cuif et al. 2015). Damselfish have relatively short larval durations (Bernardi et al. 2001) and the lack of notable reef structure on the NWS, particularly near the Wandoo oilfield, makes it unlikely that juveniles are recruiting from surrounding natural environments. Post-settlement movements of small reef-dependent fish, such as basslets (*Pseudanthias* sp.) and damselfish, is generally restricted to <50 m (Frederick 1997, Turgeon et al. 2010), hence it is likely that these fish are being produced at the Wandoo platforms rather than being attracted as adults or intercepted as larvae from the surrounding areas that lack natural reefs. The observation of a juvenile red bass at 15 m indicates that the midwater habitat may serve a nursery function for larger demersal species as well, however further investigation is needed.

The diet of larger demersal species specific to the NWS comprises of many of the smaller fish observed in the shallow midwater sections, particularly damselfish (Farmer & Wilson 2011). The lack of notable reef structure surrounding both Wandoo platforms and the known dietary preferences suggests that *in situ* predation may be occurring, with the larger demersal fish observed at depth feeding on (and up) the platform rather than in the wider surrounding habitat. Diel foraging movements in demersal species can be vertical into the water column (Beamish

1966, Neilson & Perry 1990, Gauthier & Rose 2002) and horizontal along the seabed (Harvey et al. 2012a). Bond et al. (2018a) observed diel shifts in species assemblages along an oil pipeline on the NWS, with the fish assemblage observed during the day being significantly different to the assemblage observed at night. This change in assemblage was due to grouper and snapper moving off the pipeline to feed at night. It is therefore possible that the demersal fish at Wandoo move out from the base of the platform and utilise the midwater habitat for feeding to some extent. The lack of shallow natural reefs surrounding the Wandoo platforms that could harbour populations of smaller reef fish (that comprise the majority of demersal species' diets) further increases the likelihood that predatory behaviours are occurring on and up the platform itself rather than the surrounding benthic environment. Farmer & Wilson (2011) did note, however, that many snapper species (*Lutjanus* sp.) consume herring (Clupeidae spp.), a taxon that was commonly found at depth. The vertical movements and feeding behaviours of fish associated with oil platforms therefore requires further study.

The distinct vertical gradient in attributes of the fish assemblage at both Wandoo platforms requires consideration regarding future decommissioning policy. Under current legislation, complete removal of all structures is the most likely scenario – a process that will eliminate most of the existing marine life (Claisse et al. 2015, Pondella et al. 2015), particularly when surrounded by flat sediments. If *in situ* reefing of the Wandoo platforms is considered, then the likely alternative would be topping at 26 m similar to other shallow water platforms (30-80 m) in the US (Ajemian et al. 2015, Claisse et al. 2015). Topping the Wandoo platforms could result in the potential loss of 21-45% of the taxa present on the active platform, mostly the smaller reef fish. Although some of the smaller fish that were only present in shallower portions (<22 m) of the platform do have depth ranges down to 50 m, increased predatory pressure from larger demersal species on the remaining base structure would make survival unlikely. Topping would therefore result in a reduction in the richness and abundance of the standing platform, as well as alter the composition and feeding ecology of fish associating with the structure. The larger demersal species, however, may be less affected and much of the existing biomass may be retained. This is commonly observed in the US, whereby the negative effects of topping are limited to pelagic planktivores and typically nearshore species like blacksmith (*Chromis punctipinnis*), whilst deeper-dwelling demersal species remain relatively unchanged (Wilson et al. 2006, Love et al. 2012, Claisse et al. 2015). Toppling is also a possibility and has the potential to negatively impact the ecology by removing the shallow component of platforms, however this is an unlikely option for the Wandoo B platform as it is a CGS facility.

Consideration should be given to the possibility of leaving the Wandoo platforms standing upright, with the deck removed and navigational aids in place, as much of the ecological value in terms of composition, abundance and richness exists in the shallow midwater habitat of the platforms.

The findings in this study have important implications for the commissioning of future offshore renewable energy sources. The global push for renewable energy production provides a new opportunity to incorporate structural design elements that may enhance fish production and add ecological value. Offshore wind and wave energy installations are increasing in number (Langhamer 2012, Reubens et al. 2014) and provide a fixed structure in the marine environment, similar in nature to offshore oil platforms. Unlike hydrocarbon extraction, renewable energy production is not restricted by a productive timeframe and provides an opportunity to apply our understanding of platform ecology into the design of these new offshore structures which will likely be active over a longer-term period. Applying similar structural design elements from successful artificial reefs and productive offshore platforms to future offshore renewable infrastructure can provide numerous ecosystem benefits. The results of this study demonstrate that high vertical relief and structural complexity of hard substrate are crucial components to enhancing ecosystem value. Furthermore, repurposing obsolete platforms into offshore renewable energy infrastructure provides an opportunity to maintain the marine life that has accrued on oil and gas structures for decades previous.

A number of limitations were present in this study. Firstly, the haphazard nature of ROV video archives limited replication of transects for each shaft and results should be treated with caution. However, all trends were consistent and provide insight into fish distributions with depth. The lack of measurements due to the single camera limited accurate representation of biomass distributions and life history stages. The FOV requirement, whereby the structure should take up 60-80% of the FOV, was not the most effective way of sampling two different sized structures. For example, the main shaft on Wandoo A is only 2.5 m in diameter, whilst each shaft on Wandoo B is 11 m. For structures at Wandoo A to comprise 60-80% of the FOV, the ROV does not require to be as far away from the structure as would be necessary at the wider shafts at Wandoo B. Furthermore, WNA had open space between the main shaft and adjacent risers, allowing for many pelagic fish to be identified swimming in the water column behind the shaft and resulting in high abundance counts. Future research on the ecology of offshore platforms should aim for greater standardisation in methodology, with video transects being consistent in speed and distance from the structure. Video surveys should also be conducted on the surrounding benthic environment and nearby natural reefs to compare the attributes of the fish assemblage on the Wandoo platforms to those in natural environments.

5.0 Conclusion

This study is one of the first to utilise industry ROV video to analyse the vertical distributions of fish populations on an offshore oil platform in Australia. Using existing video archives collected during standard industry operations presents a resource that requires further utilisation for scientific purposes, however the low video quality and haphazard sampling method of previous ROV surveys limits their use in standardised and replicable studies. Significant improvements can be made to future ROV surveys to align with standard scientific practice and increase the value of this footage for ecological research. Assessments of the historical ROV archives has demonstrated the importance of vertical relief on the Wandoo oil platforms, with richness and abundance of fish being greatest at shallow midwater sections of platforms. Furthermore, the composition of species associating with the platforms at various depths changed significantly. If decommissioning of the Wandoo platforms *in situ* is considered, most likely by topping at 26 m below the surface, then reductions to the number and abundance of fish associating with the platform would occur, and the taxa remaining after decommissioning would be considerably different to those present on the active platform. Much of the existing biomass, however, may be retained. Decision-makers must consider the value of the vertical relief provided by oil platforms when legislating decommissioning policy in the future.

References

Adobe (2019) Adobe Media Encoder. https://www.adobe.com/au/products/media-encoder.ht

Ajemian MJ, Wetz JJ, Shipley-Lozano B, Dale Shively J, Stunz GW (2015) An analysis of artificial reef fish community structure along the northwestern gulf of Mexico Shelf: Potential impacts of “rigs-to-reefs” Programs. PLoS One 10:1–23

Almany G, Berumen M, Thorrold S, Planes S, Jones G (2007) Local replenishment of coral reef fish populations in a marine reserve. Science 316:742–744

Anderson M, Gorley RN, Clarke KR (2008) PERMANOVA + for PRIMER: Guide to software and statistical methods.

Ars F, Rios R (2017) Decommissioning: A call for a new approach. In: Offshore Technology Conference.p 1–7

Beamish F (1966) Vertical migration by demersal fish in the Northwest Atlantic. J Fish Res Board Canada 23:109–139

Bernardi G, Holbrook SJ, Schmitt RJ (2001) Gene flow at three spatial scales in a coral reef fish, the three-spot dascyllus, *Dascyllus trimaculatus*. Mar Biol 138:457–465

Boettiger C, Lang DT, Wainwright PC (2012) Rfishbase: Exploring, manipulating and visualizing FishBase data from R. J Fish Biol 81:2030–2039

Bohnsack JA (1989) Are high densities of fishes at artificial reefs the results of habitat limitation or behavioural preference? Bull Mar Sci 44:631–645

Bonaca MO, Lipej L (2005) Factors affecting habitat occupancy of fish assemblage in the Gulf of Trieste (Northern Adriatic Sea). Mar Ecol 26:42–53

Bond T, Langlois TJ, Partridge JC, Birt MJ, Malseed BE, Smith L, McLean DL (2018a) Diel shifts and habitat associations of fish assemblages on a subsea pipeline. Fish Res 206:220–234

Bond T, Partridge JC, Taylor MD, Cooper TF, McLean DL (2018b) The influence of depth and a subsea pipeline on fish assemblages and commercially fished species.

Bond T, Partridge JC, Taylor MD, Langlois TJ, Malseed BE, Smith LD, McLean DL (2018c) Fish associated with a subsea pipeline and adjacent seafloor of the North West Shelf of Western Australia. Mar Environ Res 141:53–65

Bouchet PJ, Meeuwig JJ (2015) Drifting baited stereo-videography: A novel sampling tool for surveying pelagic wildlife in offshore marine reserves. Ecosphere 6:1-29

Brokovich E, Einbinder S, Shashar N, Kiflawi M, Kark S (2008) Descending to the twilight-zone: Changes in coral reef fish assemblages along a depth gradient down to 65 m. Mar Ecol Prog Ser 371:253–262

Bull AS, Love MS (2019) Worldwide oil and gas platform decommissioning: A review of practices and reefing options. Ocean Coast Manag 168:274–306

Cappo M, Harvey ES, Shortis M (2006) Counting and measuring fish with baited video techniques - an overview. In: Australian Society for Fish Biology: Workshop Proceedings.p 101–114

Claisse JT, Pondella DJ, Love M, Zahn LA, Williams CM, Bull AS (2015) Impacts from partial removal of decommissioned oil and gas platforms on fish biomass and production on the remaining platform structure and surrounding Shell mounds. PLoS One 10:1–19

Claisse JT, Pondella DJ, Love M, Zahn LA, Williams CM, Williams JP, Bull AS (2014) Oil platforms off California are among the most productive marine fish habitats globally. Proc Natl Acad Sci 111:15462–15467

Clarke RK, Gorley RN (2006) PRIMER v6: user manual/tutorial. Primer E: Plymouth

Cuif M, Kaplan DM, Fauvelot C, Lett C, Vigliola L (2015) Monthly variability of self-recruitment for a coral reef damselfish. Coral Reefs 34:759–770

Dauterive L (2000) Rigs-to-Reefs policy, progress, and perspective. Report to U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. 2000. OCS Report MMS 2000–073.

Department of Industry Innovation and Science (2017) Resources and Energy Quarterly.

Farmer BM, Wilson SK (2011) Diet of finfish targeted by fishers in North West Australia and the implications for trophic cascades. Environ Biol Fishes 91:71–85

Fitzpatrick C, McLean D, Harvey ES (2013) Using artificial illumination to survey nocturnal reef fish. Fish Res 146:41–50

Fowler AM, Booth DJ (2012) Evidence of sustained populations of a small reef fish on artificial structures. Does depth affect production on artificial reefs? J Fish Biol 80:613–629

Fowler AM, Macreadie PI, Booth DJ (2015) Should we "reef" obsolete oil platforms? Proc Natl Acad Sci 112:102

Frederick JL (1997) Post-settlement movment of coral reef fishes and bias in survival estimates. Mar Ecol Prog Ser 150:65–74

Friedlander AM, Parrish JD (1998) Habitat characteristics affecting fish assemblages on a Hawaiian coral reef. J Exp Mar Bio Ecol 224:1–30

Froese R, Pauly D (2019) FishBase. http//:www.fishbase.org

Gass SE, Roberts JM (2006) The occurrence of the cold-water coral Lophelia pertusa (Scleractinia) on oil and gas platforms in the North Sea: Colony growth, recruitment and environmental controls on distribution. Mar Pollut Bull 52:549–559

Gauthier S, Rose GA (2002) Acoustic observation of diel vertical migration and shoaling behaviour in Atlantic redfishes. J Fish Biol 61:1135–1153

Harvey ES, Butler JJ, McLean DL, Shand J (2012a) Contrasting habitat use of diurnal and nocturnal fish assemblages in temperate Western Australia. J Exp Mar Bio Ecol 426–427:78–86

Harvey ES, Newman SJ, McLean DL, Cappo M, Meeuwig JJ, Skepper CL (2012b) Comparison of the relative efficiencies of stereo-BRUVs and traps for sampling tropical continental shelf demersal fishes. Fish Res 125–126:108–120

Horthorn T, Bretz F, Westfall P (2008) Simultaneous inference in general parametric models. Biometrical J 50:346–363

Jones GP, Milicich MJ, Emslie MJ, Lunow C (1999) Self-recruitment in a coral reef fish population. Environ Prot 402:802–804

Jones GP, Planes S, Thorrold SR (2005) Coral reef fish larvae settle close to home. Curr Biol 15:1314–1318

Kashubsky M, Morrison A (2013) Security of offshore oil and gas facilities: exclusion zones and ships' routeing. Aust J Marit Ocean Aff 5:1–10

Kleiber C, Zeileis A (2008) Applied Econometrics with R. New York Springer-Verlag. https://CRAN.R-project.org/package=AER

Kulbicki M, Guillemot N, Amand M (2005) A general approach to length-weight relationships for New Caledonian lagoon fishes. Cybium 29:235–252

Langhamer O (2012) Artificial reef effect in relation to offshore renewable energy Conversion: State of the Art. Sci World J 2012:1–8

Letessier TB, Meeuwig JJ, Gollock M, Groves L, Bouchet PJ, Chapuis L, Vianna GMS, Kemp K, Koldewey HJ (2013) Assessing pelagic fish populations: The application of demersal video techniques to the mid-water environment. Methods Oceanogr 8:41–55

Love MS, Nishimoto MM (2012) Completion of fish assemblage surveys around manmade structures and natural reefs off california. Marine Science Institute, University of California, Santa Barbara, California. BOEM OCS Study 2012-020.

Love MS, Nishimoto M, Clark S, Schroeder DM (2012) Recruitment of young-of-the-year fishes to natural and artificial offshore structure within central and southern California waters, 2008-2010. Bull Mar Sci 88:863–882

Love MS, Schroeder DM, Lenarz W, MacCall A, Bull AS, Thorsteinson L (2006) Potential use of offshore marine structures in rebuilding an overfished rockfish species, bocaccio (*Sebastes paucispinis*). Fish Bull 104:383–390

Love MS, Yoklavich M, Schroeder DM (2009) Demersal fish assemblages in the Southern California Bight based on visual surveys in deep water. Environ Biol Fishes 84:55–68

Macreadie PI, Fowler AM, Booth DJ (2011) Rigs-to-reefs: Will the deep sea benefit from artificial habitat? Front Ecol Environ 9:455–461

Macreadie PI, McLean DL, Thomson PG, Partridge JC, Jones DOB, Gates AR, Benfield MC, Collin SP, Booth DJ, Smith LL, Techera E, Skropeta D, Horton T, Pattiaratchi C, Bond T, Fowler AM (2018) Eyes in the sea: Unlocking the mysteries of the ocean using industrial, remotely operated vehicles (ROVs). Sci Total Environ 634:1077–1091

McLean DL, Macreadie P, White DJ, Thomson PG, Fowler A, Gates AR, Benfield M, Horton T, Skropeta D, Bond T, Booth DJ, Techera E, Pattiaratchi C, Collin SP, Jones DOB, Smith L, Partridge JC (2018a) Understanding the global scientific value of industry ROV data to quantify marine ecology and guide offshore decommissioning strategies. In: Offshore Technology Conference.p 10

McLean DL, Partridge JC, Bond T, Birt MJ, Bornt KR, Langlois TJ (2017) Using industry ROV videos to assess fish associations with subsea pipelines. Cont Shelf Res 141:76–97

McLean DL, Taylor MD, Partridge JC, Gibbons B, Langlois TJ, Malseed BE, Smith LD, Bond T (2018b) Fish and habitats on wellhead infrastructure on the north west shelf of Western Australia. Cont Shelf Res 164:10–27

National Energy Resources Australia (2016) Oil & gas industry competitiveness assessment.

National Offshore Petroleum Safety and Environmental Management Authority (2017) Decommissioning offshore petroleum facilities in commonwealth waters.

Neilson J, Perry R (1990) Diel vertical migrations of marine fishes: An obligate or facultative process? Adv Mar Biol 26:115–168

Parente V, Ferreira D, Moutinho dos Santos E, Luczynski E (2006) Offshore decommissioning issues: Deductibility and transferability. Energy Policy 34:1992–2001

Pinheiro J, Bates D, DebRoy S, Sarkar D, Team RC (2019) nlme: Linear and Nonlinear Mixed Effects Models. R Packag version 31-140. https://CRAN.R-project.org/package=nlme

Pondella DJ, Zahn LA, Love MS, Siegel D, Bernstein BB (2015) Modeling fish production for southern California’s petroleum platforms. Integr Environ Assess Manag 11:584–593

Pradella N, Fowler AM, Booth DJ, Macreadie PI (2014) Fish assemblages associated with oil industry structures on the continental shelf of north-western Australia. J Fish Biol 84:247–255

Protocol to the London Dumping Convention (1996) London Protocol.

R Core Team (2015) A language and environment for statistical computing. R Found Stat Comput Vienna, Austria. https://www.r-project.org/

Reubens JT, Degraer S, Vincx M (2014) The ecology of benthopelagic fishes at offshore wind farms: A synthesis of 4 years of research. Hydrobiologia 727:121–136

Schroeder DM, Love MS (2004) Ecological and political issues surrounding decommissioning of offshore oil facilities in the Southern California Bight. Ocean Coast Manag 47:21–48

SeaGIS Pty Ltd (2017) EventMeasure Stereo. https://www.seagis.com.au/event.html

Sommer B, Fowler AM, Macreadie PI, Palandro DA, Aziz AC, Booth DJ (2019) Decommissioning of offshore oil and gas structures – Environmental opportunities and challenges. Sci Total Environ 658:973–981

Stap T van der, Coolen J, Lindeboom H (2016) Marine fouling assemblages on offshore gas platforms in the Southern North Sea: effects of depth and distance from shore on biodiversity. PLoS One 11:e0146324

Techera EJ, Chandler J (2015) Offshore installations, decommissioning and artificial reefs: Do current legal frameworks best serve the marine environment? Mar Policy 59:53–60

Thomson PG, Fowler AM, Davis AR, Pattiaratchi CB, Booth DJ (2018) Some old movies become classics – A case study determining the scientific value of ROV inspection footage on a platform on Australia’s North West Shelf. Front Mar Sci 5:1–18

Turgeon K, Robillard A, Grégoire J, Duclos V, Kramer DL, Turgeon K, Robillard A, Gr J, Duclos V, Kramer DL (2010) Functional connectivity from a reef fish perspective: behavioral tactics for moving in a fragmented landscape. Ecology 91:3332–3342

United Nations (1982) United Nations Convention on the Law of the Sea.

Vermillion Energy (2019) Australian Operations. https://www.vermilionenergy.com/our-operations/aus

Wilson SK, Babcock RC, Fisher R, Holmes TH, Moore JAY, Thomson DP (2012) Relative and combined effects of habitat and fishing on reef fish communities across a limited fishing gradient at Ningaloo. Mar Environ Res 81:1–11

Wilson CA, Miller MW, Allen YC, Boswell KM, Neiland DL (2006) Effects of depth, location, and habitat type on relative abundance and species composition of fishes associated with petroleum platforms and Sonnier Bank in the Northern Gulf of Mexico. Report to U.S. Department of Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. 2006. OCS Study MMS 2006–037.

Appendices

Appendix 1. List of taxa observed at each shaft (WNA, WNB1, WNB3) with associated common lengths and trophic levels adapted from FishBase (Froese and Pauly 2019) and Kulbicki et al. (2005). Size classes are large (L; >50 cm), medium (M; 25-50 cm) and small (S; <25 cm).

Family	Species	Common Name	Common Length	Size Class	Trophic Level	WNA	WNB1	WNB3
Acanthuridae	Acanthuridae sp	Surgeonfish	45.00	M	2.30	X	X	
	Acanthurus grammoptilus	Finelined surgeonfish	28.44	M	2.32	X	X	
	Acanthurus mata	Elongate surgeonfish	28.44	M	2.53		X	
	Acanthurus sp	Surgeonfish	28.44	M	2.32	X	X	
	Ctenochaetus sp	Bristletooth tangs	18.00	S	2.00	X		
	Naso sp	Unicornfish	45.00	M	2.42	X		
Apogonidae	Apogonidae sp	cardinalfish	13.88	S	3.54	X		
	Rhabdamia gracilis	Luminous cardinalfish	8.00	S	3.26	X		
Balistidae	Balistidae sp	Triggerfish	45.75	M	3.36	X		
Blenniidae	*Aspidontus taeniatus*	False cleanerfish	12.50	S	3.75		X	
	Blenniidae sp	Combtooth blenny	12.45	S	2.30	X	X	X
	Cirripectes sp	Combtooth blenny	12.50	S	2.04	X		
	Ecsenius bicolor	Bicolor blenny	12.50	S	2.00		X	
	Meiacanthus atrodorsalis	Eyelash fangblenny	12.50	S	3.45	X		
	Meiacanthus sp	Fangblenny	12.50	S	3.27	X		
	Plagiotremus rhinorhynchos	Bluestriped fangblenny	12.50	S	4.50		X	X
	Plagiotremus sp	Fangblenny	12.50	S	4.27	X	X	X
	Plagiotremus tapeinosoma	Piano fangblenny	12.50	S	3.84	X		
Caesionidae	*Caesio teres*	Yellow and blueback fusilier	26.60	M	3.40		X	
Carangidae	*Alepes vari*	Herring scad	30.00	M	3.65	X		X
	Carangidae sp	Jack/trevally	69.75	L	3.85	X	X	X
	Carangoides coeruleopinnatus	Coastal trevally	30.00	M	4.44			X
	Carangoides fulvoguttatus	Yellowspotted trevally	90.00	L	4.40	X	X	X
	Carangoides sp	Trevally	44.43	M	4.19	X		X
	Caranx ignobilis	Giant trevally	100.00	L	4.20	X		X
	Caranx melampygus	Bluefin trevally	60.00	L	4.50		X	X
	Caranx sexfasciatus	Bigeye trevally	60.00	L	4.50	X		
	Caranx sp	Trevally	53.85	L	3.97	X	X	X
	Elagatis bipinnulata	Rainbow runner	90.00	L	3.93	X		
	Gnathanodon speciosus	Golden trevally	75.00	L	3.84	X		
Chaetodontidae	*Chaetodon* sp	Butterflyfish	14.10	S	3.18		X	X
	Heniochus acuminatus	Longfin bannerfish	15.00	S	3.45	X	X	X
	Heniochus sp	Bannerfish	15.00	S	3.47		X	X
Cirrhitidae	*Cirrhitichthys aprinus*	Spotted hawkfish	20.33	S	3.49	X	X	X
	Cirrhitichthys falco	Dwarf hawkfish	20.33	S	3.96		X	X
	Cirrhitichthys oxycephalus	Coral hawkfish	20.33	S	4.01		X	
	Cirrhitichthys sp	Hawkfish	20.33	S	3.87		X	X
Clupeidae	Clupeidae sp	Herring	18.00	S	3.15	X		
Echeneidae	*Echeneis naucrates*	Live sharksucker	66.00	L	3.70		X	
Ephippidae	Ephippidae sp	Batfish	37.50	M	3.44	X		
	Platax orbicularis	Orbicular batfish	28.40	M	3.33	X		X
	Platax sp	Batfish	28.40	M	3.52	X		X

Appendix 1. (*Continued*)

Family	**Species**	**Common Name**	**Common Length**	**Size Class**	**Trophic Level**	**WNA**	**WNB1**	**WNB3**
	Platax teira	Longfin batfish	28.40	M	3.95	X	X	X
	Zabidius novemaculeatus	Ninespine batfish	28.40	M	3.50	X		
Ginglymostomatidae	*Nebrius ferrugineus*	Tawny nurse shark	250.00	L	4.10		X	
Haemulidae	Haemulidae sp	Sweetlip	56.25	L	3.63		X	
	Plectorhinchus gibbosus	Brown sweetlips	41.25	M	3.60	X	X	
Juvenile	Juvenile sp	Juvenile	#N/A	#N/A	#N/A	X		
Labridae	*Anampses* sp	Wrasse	25.57	M	3.47	X		
	Bodianus diana	Diana's hogfish	33.50	M	3.40		X	
	Bodianus sp	Hogfish	33.50	M	3.45		X	
	Cheilinus fasciatus	Redbreasted wrasse	39.00	M	3.37		X	
	Choerodon sp	Tuskfish	25.57	M	3.52		X	
	Hemigymnus fasciatus	Barred thicklip	25.57	M	3.50	X	X	
	Labridae sp	Wrasse	69.75	L	3.49	X	X	X
	Labroides dimidiatus	Bluestreak cleaner wrasse	25.57	M	3.50		X	
	Thalassoma amblycephalum	Bluehead wrasse	14.50	S	3.10	X	X	
	Thalassoma lunare	Moon wrasse	14.50	S	3.50	X	X	
	Thalassoma sp	Wrasse	14.50	S	3.53	X	X	X
Lethrinidae	Lethrinidae sp	Emperor	64.50	L	3.66			X
Lutjanidae	Lutjanidae sp	Snapper	69.00	L	3.94		X	X
	Lutjanus bohar	Red bass	76.00	L	4.30		X	
	Lutjanus erythropterus	Crimson snapper	45.00	M	4.50	X		X
	Lutjanus gibbus	Humpback red snapper	45.00	M	4.10		X	
	Lutjanus lemniscatus	Yellowstreaked snapper	35.00	M	3.98	X	X	
	Lutjanus sp	Snapper	41.63	M	3.97	X	X	X
Nomeidae	*Psenes* sp	Driftfish	23.00	S	3.65	X		
Pomacanthidae	*Pomacanthus imperator*	Emperor angelfish	29.75	M	2.70	X	X	X
	Pomacanthus semicirculatus	Semicircle angelfish	29.75	M	2.69		X	
	Pomacanthus sp	Angelfish	29.75	M	2.77			X
Pomacentridae	*Abudefduf* sp	Sergeant-major	10.00	S	2.89	X		
	Abudefduf vaigiensis	Indo-Pacific sergeant	10.00	S	2.60	X	X	X
	Chromis fumea	Smokey chromis	13.33	S	3.40	X	X	
	Chromis sp	Puller	13.33	S	3.08	X	X	
	Chromis westaustralis	West Australian chromis	13.33	S	2.71		X	X
	Dascyllus reticulatus	Headband humbug	6.00	S	3.13	X	X	
	Dascyllus trimaculatus	Threespot humbug	6.00	S	2.80	X	X	X
	Lepidozygus tapeinosoma	Fusilier damselfish	11.00	S	3.40		X	
	Neoglyphidodon melas	Bowtie damselfish	11.00	S	3.40		X	
	Neopomacentrus azysron	Yellowtail demoiselle	11.00	S	3.40	X		
	Neopomacentrus cyanomos	Regal demoiselle	11.00	S	3.41	X	X	X
	Neopomacentrus sp	Demoiselle	11.00	S	3.41		X	
	Pomacentridae sp	Damselfish	13.35	S	2.80	X	X	X
	Pomacentrus coelestis	Neon damselfish	11.00	S	3.18	X	X	X

Appendix 1. (*Continued)*

Family	Species	Common Name	Common Length	Size Class	Trophic Level	WNA	WNB1	WNB3
	Pomacentrus grammorhynchus	Bluespot damsel	11.00	S	2.72		X	
	Stegastes fasciolatus	Pacific gregory	9.67	S	2.20		X	
	Stegastes obreptus	Western gregory	9.67	S	2.00		X	
	Stegastes sp	Gregory	9.67	S	2.32		X	
Rachycentridae	*Rachycentron canadum*	Cobia	110.00	L	4.00	X		
Scaridae	*Chlorurus* sp	Parrotfish	29.89	M	2.09	X		X
	Scarus chameleon	Chameleon parrotfish	24.80	M	2.00	X		
	Scarus ghobban	Blue-barred parrotfish	30.00	M	2.00	X		X
	Scarus rubroviolaceus	Ember parrotfish	35.70	M	2.00			X
	Scarus sp	Parrotfish	35.70	M	2.02	X	X	X
Serranidae	*Cephalopholis argus*	Peacock rockcod	40.00	M	4.50	X		
	Cephalopholis boenak	Brownbarred rockcod	27.56	M	4.10		X	
	Cephalopholis miniata	Coral rockcod	27.56	M	4.30	X		
	Cephalopholis sonnerati	Tomato rockcod	30.00	M	3.81	X		
	Cephalopholis sp	Rockcod	27.56	M	4.07	X	X	X
	Cromileptes altivelis	Humpback grouper	40.30	M	4.50		X	
	Epinephelus areolatus	Areolate grouper	35.00	M	3.70	X	X	
	Epinephelus bilobatus	Frostback rockcod	59.21	L	3.70		X	X
	Epinephelus coioides	Orange-spotted grouper	59.21	L	3.98	X	X	X
	Epinephelus multinotatus	Rankin cod	75.00	L	3.86	X	X	X
	Epinephelus sp	Grouper	59.21	L	3.96	X	X	X
	Pseudanthias rubrizonatus	Red-belted anthias	9.67	S	3.40	X	X	
	Pseudanthias sp	Basslet	9.67	S	3.39	X		
	Serranidae sp	Groupers	96.00	L	3.86		X	X
Sphyraenidae	*Sphyraena barracuda*	Great barracuda	140.00	L	4.50	X	X	
	Sphyraena sp	Barracuda	65.69	L	4.32		X	
Tetraodontidae	*Arothron hispidus*	White-spotted puffer	54.00	L	3.17	X		X
Zanclidae	*Zanclus cornutus*	Moorish idol	21.00	S	2.49		X	X