

Enhanced ROV Survey of Tropical Fish and Benthic Communities Associated With Shallow Oil and Gas Platforms

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Abstract

Understanding the ecology of oil and gas infrastructure in our oceans is required to inform decommissioning such that environmental impacts are minimised, and benefits maximised. This study equipped an industrial remotely operated vehicle (ROV) with a stereo-video system and collected seven hours of high-definition imagery of two platform jackets, for assessments of benthic (type, density, complexity) and fish assemblages (richness, abundance, length) present. Harriet Alpha (25 m depth) and Gibson/South Plato (8 m depth) are located *ca.* 120 km offshore of north-west Australia, adjacent to Varanus Island. Twenty-one 'classes' of benthic biota were observed in high density, with little bare structure on either platform. Encrusting sponges (average 19% cover per virtual quadrat), barnacles (17%) and sponges (16%) were common on Gibson/South Plato while encrusting sponges (16%) and macroalgae (18%) were ubiquitous on quadrats on Harriet Alpha. The sun coral *Tubastraea faulkneri* was common on Harriet Alpha (38% of quadrats), though coverage was low (<6%). A total of 102 fish species from 27 families were observed. This included 33 fishery target species with an estimated relative mass of 116 kg on Gibson/South Plato and 299 kg on Harriet Alpha, with these species typically concentrated near the seafloor-structure interface. Differences in benthic biota communities present on each platform likely reflect spatial variations in oceanographic processes, proximity to natural habitats and the age, configuration, cleaning regime and depth of the structures themselves. This study demonstrates the value of adding stereo-video systems to ROVs to undertake rapid scientific surveys of oil and gas infrastructure.

Introduction

There are presently *ca.* 12,000 offshore oil and gas (O&G) platforms in oceans around the world with highest concentrations in the Gulf of Mexico and North Sea (Ars and Rios, 2017; Jouffray et al., 2020). Platforms most often exist in sediment-dominated marine environments where they provide novel habitat incomparable to any natural reef feature (Love et al. 2019; Schulze et al. 2020). Most are conventional fixed steel or concrete platforms, and they can range in size from small monopods in depths < 15 m to large complex structures in depths > 300 m.

Platforms have been shown to have a variety of positive and negative impacts on marine ecosystems. Activities associated with these structures may facilitate the establishment and spread of non-native species (Page et al. 2019), the platforms introduce a range of stimuli that can alter species' behaviours (lights, noise; Montevecchi 2006; Todd et al. 2020a) and introduce contaminants and nutrients into marine ecosystems (Breuer et al. 2008; Adewole et al. 2010). On the other hand, platforms, often protected by 500 m fishing exclusion zones (*de facto* marine reserves; Schroeder and Love 2004), provide hard structure for larval recruitment and settlement (Love et al. 2006; Nishimoto et al. 2019), habitat that promotes biodiversity (McLean et al. 2020; Todd et al. 2020b), increased fish biomass (Streich et al. 2017; Love et al. 2019) and boost local fish productivity (Claisse et al, 2014; 2019; Smith et al. 2016; Meyer-Gutbrod et al. 2020). The habitat value of offshore platforms appears greatest when they exist in oligotrophic ecosystems where natural hard substrata is limited (Friedlander et al. 2014).

In Australia, only a small number of published studies have examined marine ecology in relation to platforms, despite 57 fixed platform structures existing in marine ecosystems for anywhere up to 60 years (i.e. Furnas and Mitchell 2003; Neira 2005; McLean et al. 2019) and a requirement for data to inform decommissioning decisions. In the south-east of Australia, a plankton survey study by Neira (2005) around nine offshore platforms documented a diversity of larval and early-stage juvenile fishes. In the north-west, remotely operated vehicle (ROV) surveys of Woodside Energy's 'Goodwyn Alpha,' (installed in 1995, 140 km offshore, 130 m depth) found diverse and abundant array of fish, invertebrate and benthic communities that change in composition and abundance from the surface to the seabed (Thomson et al. 2018; McLean et al. 2019). Acoustic telemetry revealed that whale sharks (*Rhincodon typus*) were drawn to two platforms (North Rankin, Pluto) on the north-west shelf of Western Australia (Thomson et al. in press). Also, in the north-west, research by Furnas and Mitchell (2003) examined biological and chemical oceanographic processes near to Harriet Alpha platform and documented well mixed and highly productive waters. Across the globe, research is discovering each O&G structure possesses a unique marine community that reflects the influence of the structure itself (height, complexity, age, materials, cleaning regime, platform discharges, etc) and a vast array of site-specific environmental variables (depth, temperature, wave exposure, etc) (McLean et al. 2018; Claisse et al. 2019). As such, an understanding of the habitat value of platforms, to inform decommissioning decisions, will likely require site/asset-specific information.

The present study assessed marine communities associated with two shallow-water platform jacket structures located adjacent to the Lowendal Islands, 120 km offshore on Australia's north-west shelf. Marine ecosystems in this remote offshore region of north-west Australia face multiple pressures from cyclones, increasing seawater temperatures and episodic marine heatwaves associated with climate change (Moore et al. 2012; Pearce and Feng 2013; Gilmour et al. 2019). Additional pressures include fishing (limited and sporadic; Ryan et al. 2019) and activities associated with oil and gas production (dredging, shipping, noise, lights) (WAMSI 2019; Evans et al. 2018; Wilson et al. 2019). In the 1950s, the nearby Montebello Islands were also subject to nuclear weapon tests (Child and Hotchkis 2013). Despite these pressures, a high diversity of marine flora and fauna exist across the mangrove, seagrass, macroalgal dominated limestone reefs and coral habitats that surround the Montebello, Lowendal and Barrow Islands (Allen 2000; Bancroft 2009; Wilson 2013; Richards and Rosser 2012; Evans et al. 2014; DBCA et al. in prep). Using an industrial ROV augmented with high-definition stereo-video cameras, this study aimed to describe the fish, mobile invertebrate and benthic communities associated with two shallow-water platforms. We discuss the findings in the context of marine communities present in natural ecosystems in this region and elsewhere on platforms.

Methods And Materials

Study site and platform jacket descriptions

The two platform jackets (herein termed 'platforms') that were the focus of this study are operated by Santos Ltd. Both platforms are located near to Veranus Island, the largest of the Lowendal Islands *ca.*

120 km off the north-west coast of Western Australia, an area that possesses a dynamic oceanographic environment influenced by strong tides, cyclonic storms, long-period swells and internal tides. The Lowendal Islands are located between the Montebello Islands (to the north) and Barrow Island (to the south) and are in-part encompassed by the Barrow Islands Marine Management Area (BIMMA; DBCA et al. in prep). The BIMMA covers 114,693 ha and was zoned in 2004 to manage significant conservation, fishing, diving and heritage values (DEC 2007) recognising the complex and diverse seabed topography, benthic and fish communities (DBCA et al. in prep). Most of the BIMMA remains unzoned with a range of activities permitted, including commercial and recreational fishing.

Stereo-video recordings were obtained of both platforms from the 26th -28th of October 2020. Harriet Alpha (HA) is a convention steel platform located 6.3 km north east of Veranus Island at 20° 36' 07.78S, 115° 36' 51.07" E (Fig. 1). Operational since 1986, HA is only manned periodically with production recently suspended. The seabed surrounding HA includes low relief unconsolidated carbonate silty fine to coarse sand. Benthic communities are dominated by macrofauna (sponges, sea whips, sea stars) and infauna (polychaete worms, small crustaceans, molluscs (Santos 2019). The nearest macroalgae and coral reef communities are located ~ 2 km to the west and south-west of the platform.

The Gibson/South Plato (GSP) 'minipod' platform is situated in 8 m depth at 20° 41.741S 115° 34.044E, 12 km south-south west of HA and 4.6 km from Veranus Island (Fig. 1). Unlike HA, GSP is located within the BIMMA. Operational since 2002, GSP is located near to five other small monopod facilities together known as the 'string of pearls' (includes Simpson A and B, Victoria, Double Island and Twickenham) (Fig. 1). Rocky shores are adjacent to the platform while the seabed surrounding the structure includes a mix of shallow reefs covered by macroalgae and sponges and some deeper pavement areas where coral communities occur (Quadrant Energy 2017). Coral bommies occur within 200 m of GSP and additional seabed features noted near to the facility include large bomboras (shallow submerged reefs) (Quadrant Energy 2017).

A 500 m petroleum safety zone surrounds HA and GSP, meaning no fishing has occurred in the immediate vicinity of the platforms since 1986 in the case of HA (34 years) and 2002 for GSP (18 years).

Enhanced ROV surveys of platforms

A small stereo-video system (< 10 kg) was affixed to a Seaeye Panther-XT ROV (PXT 949) operated by Mermaid Marine. The system comprised a pair of high-definition GoPro Hero5 (black models) inwardly converged at 7° to provide an overlapping field of view. The stereo-video system uses the same camera components as those currently used in many baited remote underwater stereo-video systems (stereo-BRUVs). Cameras were set to record in 1080p video format at 30 frames per second with a medium field of view. Video cameras were calibrated pre- and post-mobilisation to ensure accurate stereo-video length measurements using the CAL software (Harvey and Shortis 1998; SeaGIS 2019). To assist in fish and habitat identification, an additional GoPro Hero5 camera was mounted in the centre of the system and programmed to take high resolution 12 Mega Pixel still photographs at 10 second intervals throughout

the sampling period. Video analysis to identify, count and measure fish was performed using the program EventMeasure Stereo (SeaGIS 2020).

No researchers could access the HA or GSP platforms during this ROV program, therefore a scientific sampling protocol and camera operation manual were developed in consultation with Industry and ROV operators to ensure that their staff were able to independently perform scientific surveys. Imagery was collected for the majority of each platform jacket from the surface to the seabed. The ROV maintained a consistent speed of *ca.* 0.5 m/s and used continuous lighting (40 W, 110 VAC, 2520 lumens, White 6500 K, 130-degree beam angle). All surveys were performed between the hours of 0700 to 1700 AWST to avoid crepuscular changes in the recorded fish assemblage.

To examine the influence of depth and platform position on fish and benthic communities for HA, we used the ROV imagery of horizontal beams near the surface, at 10 m depth and near the seafloor at 25 m depth on both sides of the platform (widest sides; Fig. 2A). Due to its small size, GSP could be surveyed in its entirety with a vertical transect that enabled viewing from one side of the structure through to the other (Fig. 2B). For comparisons between HA and GSP, we used all imagery collected during the survey which was a combination of the dedicated transects and opportunistic roaming surveys providing a more comprehensive assessment of the structure.

Stereo-video imagery analysis

Benthic community assessment

Benthic biota were assessed by placing 55 'virtual' quadrats on horizontal and vertical beams of each platform, 18 on GSP and 37 on HA. Video frames for which quadrats were assigned were those that provided a close and clear view of vertical and horizontal beams across the depth range of each structure. On HA, quadrats were placed on beams in the top section ($n = 16$; *ca.* 2–4 m), mid-section ($n = 15$; *ca.* 8–10 m) and near the seafloor ($n = 14$; *ca.* 20–25 m). On GSP, quadrats were randomly placed across the structure. The size of benthic quadrats was between *ca.* 0.4–1.5 m² based on measurements taken of the beams throughout the structure.

Virtual quadrats were analysed using TransectMeasure™ software (SeaGIS 2020), to assess benthic cover according to modified CATAMI categories (Collaborative and Annotation Tools for Analysis of Marine Imagery; Althaus et al. 2015). For each quadrat, 20 points were randomly allocated on the image, and benthos directly underneath the point identified to biota categories (e.g., macroalgae, sponges, hard corals) and morphological characteristics (e.g., encrusting, complex or taller erect forms) (see A-Table 1). For each quadrat, a measure of epibiota complexity was recorded by estimating benthic biota height according to four categories: 0: negligible, 1: low (0–20 cm), 2: medium (20–40 cm) and 3: high (> 40 cm) using the known dimensions of structural elements of each platform as a reference. Finally, for each quadrat we also estimated benthic biota density (percent cover) as 0: none, 1: < 25%, 2: 25–75%, 3: >75%.

Fish community assessment

For HA, as the ROV often backtracked and covered sections already surveyed, it was not possible to analyse the imagery in a single continuous transect without re-counting individuals. For this platform, we therefore assessed fish communities in two ways:

1) MaxN –we recorded the maximum abundance of each fish species encountered at any point in time throughout the ROV video. This provided a single conservative measure of relative abundance for each species for the entire platform, avoided recounting individuals, but likely underestimated the total abundance of each species present.

2) Horizontal transects – all fish observed on horizontal transects were counted with these transects performed just below the surface (~ 2 m depth), at 10 m depth and at the seafloor (25 m) (Fig. 2A). These horizontal transects were performed on each of the wide faces of HA giving $n = 2$ transects per depth. For GSP, we used the MaxN method (1) and as the platform was small, which likely more accurately represented abundances of each species for this structure. Those individuals that could not be confidently or consistently identified to species level were identified to the next finest taxonomic level possible. All species were assigned to a feeding guild based on dietary information obtained from Fishbase (Froese and Pauly 2021) and fishery-target species noted as those likely to be caught and retained by recreational or commercial fisheries operating in this region (Fletcher et al. 2017).

The stereo-configuration of cameras, and the calibration procedure, allows accurate and precise lengths and distances to be measured (Harvey et al. 2001). The lengths of all fish observed at the time of 'MaxN' (HA and GSP), and on each of the six horizontal transects on HA, were measured. The fork length (snout to tail fork; FL) of each fish was measured to the nearest mm while the fish was straight and orientated at an angle 45–90° to the cameras principal optical axes to maximise accuracy. For all species, the mass (M ; kg) of fish was calculated using the equation $M = aL^b$ where a is a coefficient describing body shape and condition, L is length, and b the coefficient of geometric growth in body proportions, isometric growth being indicated when $b = 3$. Values for a and b were obtained from FishBase (Froese and Pauly 2021) for all species where possible; for some species a genus average or values from a congeneric species were used.

The lengths of all fish could not be measured from video imagery as many were only visible on one camera. Approximately 12% of fish were measured as we measured only *ca.* 20% of individuals where they made up large schools (e.g., *Alepes vari*, herring scad). Baitfish were also not measured. Therefore, we derived an 'estimated mass' for all fish recorded on transects by assigning the mean size of measured conspecifics to the additional fish that were observed but for which accurate length measurements were not possible. Where necessary, the average size from congeneric species was used but when unavailable these species were excluded from mass estimates. In assigning a mean size to those that could not be measured we are assuming that conspecific schools comprise individuals of similar size, a schooling behaviour that has been theorised to reduce predation risk (Ranta et al. 1994).

Data analysis

Analyses and plots were performed using Primer-E (Clarke and Gorley 2006) with the PERMANOVA + add on (Anderson et al. 2008), and the R language for statistical computing (R Development Core Team 2019) with the plotting package ggplot2 (Wickham 2009).

The multivariate fish and habitat data sets were compared across the Harriet depth bands and for benthic habitats, also between structures in Primer-7 (Clarke and Gorley 2015) with the PERMANOVA + add on (Anderson et al. 2008). For the fish comparison, a Bray Curtis dissimilarity matrix (Anderson et al. 2006) was constructed on $\log(x + 1)$ transformed multivariate fish abundance datasets. This was used as it does not treat the absences of species as similarities and emphasizes the composition of the assemblage rather than the relative abundance of individual species (Anderson et al. 2008). The multivariate habitat data was normalised, and Euclidean distance was used to produce resemblance matrices. Both fish and benthic habitat analyses used a single factor design with unrestricted permutations of raw data with either depth (three levels) or platform (two levels – benthic data only) as fixed factors. Principle coordinate analysis (PCO) were used to determine unconstrained similarities and patterns among groups (depths, transects/quadrats). Individual species or benthic habitat types that were likely responsible for any of the observed differences were identified using Pearson correlations of their abundance with the canonical axes. A Pearson correlation of $|R| \geq 0.6$ for fish and $|R| \geq 0.5$ for benthos was used as an arbitrary cut-off to display potential relationships between individual species and the PCO axes. These relationships are graphically illustrated using vectors that are superimposed onto the PCO plot.

We compared length distributions between platforms and across the different depths of HA using kernel density estimates (KDEs) in the “gg-plot2” package in R to estimate the probability density function of the length- frequency data (Wickham, 2016). The algorithm used disperses the mass of the empirical distribution function over a regular grid of > 512 points and then uses the fast Fourier transform to combine this approximation with a discretised version of the kernel. The model then uses linear approximation to evaluate the density at the specified points with bandwidths as the standard deviation of the kernel.

Results

Benthic communities

Ten broad categories of benthic biota were assessed from imagery representing a high but unknown diversity of soft corals, sponges, hard corals, macroalgae, crustaceans, molluscs and hydroids (Supplementary Table 1). Examples of biota observed are presented in Fig. 3. The density (percent cover) of benthic biota was consistently high on both platforms ranging from 25–75%. Benthic biota height was lower on GSP (0–20 cm) than on HA (< 20 - >40 cm), where height was greatest on quadrats assessed in 20–25 m depth.

The composition of benthic communities differed among the platforms (d.f. = 1,55, MS = 4.26, Pseudo-F = 4.26, $P(\text{perm}) < 0.01$; Supplementary Table 1). The hard corals, *Tubastraea faulkneri* and *T. micranthus* were only observed on HA in depths > 10 m where they were present in low coverage (< 6%; Supplementary Table 1; Fig. 3, 4). The soft coral *Dendronephthya sp1* was also only observed on HA with an average cover of 1.5%. Generally, however, soft corals were more abundant on GSP (~ 10%; Fig. 4) and included one class unique to this platform (Melithaeidae sp1; Supplementary Table 1; Fig. 3). Also only observed on GSP were coralline algae, hydroids, branching and laminar sponges, each in very low cover. Barnacles were evident on both platforms, but in particularly high cover on GSP (mean 16.7% per quadrat) where they were observed on quadrats nearest the surface (Supplementary Table 1; Fig. 3, 4). A variety of sponge morphologies were observed on both platforms, the most common being encrusting varieties (Supplementary Table 1). The HA platform had a much higher proportion of biota that could not be identified from imagery ('other' 33%; Fig. 4). Macroalgae was evident on both platforms, but in higher cover on HA (19% on HA vs. ~3% GSP; Supplementary Table 1; Fig. 3, 4). Benthic communities on HA did not differ according to depths surveyed ($P(\text{perm}) = 0.21$).

Fish communities

A description of fish communities at Harriet Alpha and Gibson/South Plato platforms

Across both platforms, and from MaxN data, we observed 4716 fish from 102 species and 27 families (Table 1, Supplementary Table 2). Forty-nine species were unique to HA and 22 to GSP with 31 species observed at both platforms. Total fish abundance was higher on HA than on GSP, however small baitfish comprised 60% of total fish abundance observed on this platform (n = 2000). Baitfish were also abundant on GSP (n = 750) (Fig. 5). The top five most abundant fish observed on each platform (excluding baitfish) are presented in Table 1. These abundant species are typically small (< 20 cm FL), schooling, and considered non-target fishery species (with the exception of stripey snapper which is fished). No endangered (International Union for the Conservation of Nature; IUCN listed) or protected (Environmental Protection and Biodiversity Conservation; EPBC Act) species were observed on either platform.

Table 1

Summary of fish diversity and abundance for Harriet Alpha (HA) and Gibson/South Plato (GSP) platforms. Detailed information can be viewed in Supplementary Table 2.

	Both platforms	HA	GSP
Total # fish	4716	3344	1372
Total # species	102	80	53
Total # families	28	24	22
Top 5 most abundant		Pterocaesio chrysozona (300) yellowband fusilier	Glaucosoma magnificum (149) threadfin pearl perch
		Neopomacentrus cyanomos (164) regal demoiselle	Lutjanus carponotatus (100) stripey snapper
		Pomacentridae sp (150) damsel fish	Psammoperca waigiensis (78) Waigieu seaperch
		Alepes vari (139) herring scad	Caesio cuning (60) yellowtail fusilier
		Chromis fumea (102) smoky puller	Diagramma pictum (21) painted sweetlips

The proportion of the fish assemblage comprised of different families varied between the two platforms, reflecting schools of species within families such as *Glaucosoma magnificum* (threadfin pearl perch) at GSP and of pomacentrids (*N. cyanomos*, *C. fumea*), caesionids (*P. chrysozona*) and carangids (*A. vari*) at HA (Fig. 6, Table 1). The most abundant fishery targeted species were similar on both platforms (Fig. 6) and included various snapper and trevally species (Fig. 5). The most abundant fishery target species on GSP was *Lutjanus carponotatus* (stripey snapper, n = 100), followed by *Lutjanus russellii* (Moses' snapper, n = 15), *Lethrinus atkinsoni* (yellowtail emperor, n = 14), *Gnathanodon speciosus* (golden trevally, n = 13) and *Carangoides gymnostethus* (bludger trevally, n = 9) (Fig. 5, 6). Three of the top five fishery target species on GSP, were also among the top five on HA. The most abundant fishery target species on HA were *Carangoides fulvoguttatus* (turrum, n = 30), *L. carponotatus* (n = 29), *G. speciosus* (n = 17), *C. gymnostethus* (n = 16) and *Carangoides* sp. (unidentified trevally, n = 15) (Fig. 5, 6).

The size distribution of fish communities differed among the two platforms with a bimodal pattern observed at HA reflecting a high proportion of both small (< 200 mm FL) and of larger (> 350 mm FL) individuals with fewer between these sizes (Fig. 7). The mean length of fish at HA was 328 ± 12 SE mm

and the total mass of measured fish at MaxN was 645 kg. Conversely, a high proportion of the fish assemblage at GSP were of sizes 150–300 mm, where the mean length for the assemblage was 248 ± 8 SE mm (Fig. 7) and total measured mass 287 kg (Fig. 7). This reflects schools of different sized individuals at each platform and the extended depth-range of HA to include larger, typically snapper and emperor species, at the base of this jacket. The total mass of fishery target species on HA was 299 kg while on GSP it was 116 kg. Values for HA are lower than those obtained for transect measures as indicated in Sect. 4.2.2 (Fig. 9).

Fish communities across depths on Harriet Alpha

A total of 80 fish species from 24 families were observed around HA from MaxN data. Examination of the separately assessed horizontal transects revealed that total abundance of fish observed on horizontal transects was much higher at 8589 (compared to 3344 from summed MaxN), suggesting that the MaxN measurement for the entire platform was indeed a conservative estimate of total abundance, but accurate for species richness. Fish communities differed across depths (d.f. = 2,5; MS = 5054.5, Pseudo-F = 3.87; $P(MC) = 0.045$). Of these 8589 fish observed on horizontal transects, most (84%) were observed along transects performed at the seafloor. Species richness was also highest near the seafloor ($n = 50$ spp) and lowest at surface transects ($n = 9$ spp). High abundances and diversity near the seafloor reflect, primarily, the high abundance of algae/invertivore and carnivorous species observed there. Examples of these species include *Heniochus acuminatus* (longfin bannerfish), *Epinephelus coioides* (goldspotted rockcod), *Lutjanus argentimaculatus* (mangrove jack), with others presented in Fig. 8.

The distinction between fish communities observed near the surface, mid-water and at the seafloor was significant across this 25 m depth range, illustrated by the varying assemblage composition and abundance (Fig. 8) and size structure (Fig. 9). *Abudefduf vaigensis* (Indo-pacific sergeant) characterised the shallow sections of the platform (Fig. 8). Abundant in mid-water sections were several moon wrasse species (*Thalassoma* spp), damselfish (*N. cyanomos*, *Dascyllus trimaculatus*), the roundface batfish (*Platax teira*) and schools of *Alepes vari* (herring scad) (Fig. 8). At the seafloor, snappers (*Lutjanus* spp) and groupers (*Epinephelus* spp.) were abundant, in addition to schools of baitfish (unknown sp) and shortfin batfish (*Zabidius novemaculeatus*) (Fig. 8).

While baitfish were most abundant near the seafloor, as their lengths were not measured, they are not included in the length distribution modelling, resulting in the shallower and mid-water depths comprising a higher proportion of smaller-bodied fish (Fig. 9). Most fish species measured from transects at the top and middle sections of HA were < 250 mm FL, with 9 kg total measured mass near the surface and 456.7 kg mid-water. Unlike the top sections, the middle section also comprised fish species of larger sizes (250–500 mm). Length distributions at the seafloor were skewed to primarily larger-bodied species 300–700 mm FL (Figs. 8, 10), typically fishery important snappers and groupers (Fig. 8) with a total measured mass in this section of 781.8 kg from transects. Across the depth bands, total mass was 1247 kg for all fish species and 685 kg for fishery target species, a less conservative estimate than the mass derived from the MaxN data used to compare structures (Fig. 7).

Discussion

This is the first study to describe benthic and fish communities associated with two oil and gas platforms within (GSP) and immediately adjacent to (HA) the BIMMA in an area of conservation significance. The distinct benthic and fish communities observed on the two structures likely relates to their size, configuration, age, the depth of water in which they are located and their proximity to natural habitat features.

Relative to the size of the two platform structures, high fish abundance and diversity was observed. The platforms were characterised by schools of small caesionids (fusiliers) and carangids (trevallies) that swam within and around the support beams. Attraction of pelagic species such as these to physical structures that span the water column is a well-known phenomenon where such structures are often referred to as fish aggregating devices (FADs; Castro et al. 2002). These behaviours are linked to species obtaining benefits in terms of finding food, predation success, avoiding predation and increasing mating opportunities (Deudero et al. 1999; Sancho 2000). Additional behaviours were noted that suggest that platforms provide a variety of specific niche habitats that benefit different species depending upon their ecology. For example, *L. carponotatus* (stripey snapper) would 'line up' along vertical beams (Fig. 5G) while *G. magnificum* (threadfin pearl perch) would exhibit a similar behaviour but usually in the shadows beneath horizontal beams (Fig. 5E). *L. carponotatus* may form this vertical configuration to remain as close to the structure as possible, likely for shelter while the behaviour of the Australian endemic *G. magnificum* suggests it has an affinity for caves/overhang environments.

Herbivorous fish were observed in low numbers (e.g., parrotfish, surgeonfish), perhaps due to a limitation in preferred algal species present on these structures. We did not separately include 'corallivores' as a feeding guild (butterflyfishes), for we saw very few, likely due to the low amount of hard coral cover on these platforms. Conversely, invertebrate and generalist carnivores were prevalent (A-Table 2), suggesting the presence of abundant invertebrate communities within and around the platforms. A high abundance of baitfish, particularly near to the seafloor likely provides a food source supporting the higher abundance of many other predatory demersal species observed in this part of the platform. An affinity of these larger, typically predatory fish species (groupers, snappers) with the seafloor-structure interface is expected as they are predominantly reef-associated species. Although the structures observed here remain relatively consistent in their structural complexity throughout the water column, species preferring to remain near the bottom may suggest defensive behaviour against open eater predation (Rilov and Benayahu 1998). An ability to utilise the structure for shelter and to ambush prey would benefit these species. The dominance of carnivorous fish species and relatively low abundance of herbivores/corallivores is likely linked to an absence of suitable benthic biota to support high abundances of these feeding guilds on platforms.

Commercial fisheries that operate in this region include the Pilbara Trap Managed Fishery, North Coast Shark Fishery, Onslow Prawn Management Fishery, wetline, beche de mer and tropical rock lobster fisheries and shell, coral and aquarium fish collecting (DBCA et al. in prep). However, most do not operate

in the BIMMA or rarely fish within it (Newman et al. 2019; DBCA et al. in prep). Most recreational fishing occurs from charter vessels, although there is some recreational fishing from private vessels (Ryan et al. 2019). In regard to finfish, the platforms are located within the north coast bioregion where the principal fisheries (commercial trap and recreational) focus on high-value emperors, snappers and cods (Newman et al. 2019). The total estimated mass of fish across all depths at Harriet was 1247 kg (685 kg for fishery target species). McLean et al. (2019) reported a total mass of 2779 kg for the first 25 m depth bracket of a larger (125 m depth) jacket on the north-west shelf. The much higher mass reported by McLean et al. (2019) than here was due to large schools of big trevallies (*Caranx spp*) that were present at this remote offshore jacket compared to the small-bodied scad species observed at these shallower platforms. Of the top 14 species obtained in the commercial fisheries (proportion of catch), seven were observed here (*L. sebae*, *L. erythropterus*, *E. multinotatus*, *L. vitta*, *L. nebulosus*, *L. russellii*, *Plectropomus spp.*). The remaining six species not observed here all occur in deeper water or generally associate with different seabed morphologies. While it is unlikely that fishery target populations on these platforms have a significant contribution to fisheries, they do provide sanctuary for these species through an enforced exclusion zone. Research that seeks to monitor fishery target species inside and outside no-take sanctuary zones around the Montebello and Barrow Islands should seek to include oil and gas platforms. In this way, their role as *de facto* marine reserves may be assessed in addition to providing an understanding of how fish communities on these structures compare to those in surrounding natural ecosystems.

The cover of benthic biota on both platforms was high, yet diversity is unknown given that it is very difficult to identify many corals and sponges to genus or species level without physical examination of specimens. Thus, while a high diversity of biota is known for this region (Richards and Rosser 2012; Fromont et al. 2016), few distinct groups could be identified on platforms. This highlights the challenges of utilising imagery, no matter the quality, to assess the diversity of benthic communities where specimen collection or physical assessment is required. However, imagery is particularly useful for the development of reference libraries that become especially valuable when paired with specimen identifications. On GSP, some of the beams nearest the surface were dominated by barnacles (Fig. 3G). A high diversity of barnacle species exist in shallow waters of north-west Australia (Jones 2012) and their growth and settlement is positively associated with productivity (Menge et al. 2003). Presence of particular biota on various sections of platforms can be related to shading or sheering effects of currents (Love et al. 2019b). Here, high cover on GSP platform beams near the surface likely provides them with a vantage point to utilise their cirri (feathery feeding appendages) to filter feed and trap food such as plankton that may pass them by. Barnacle production on platforms has been shown to serve important ecological functions in the Gulf of Mexico where they are prey for many important commercially fished species (Reeves et al. 2018). While imagery suggests large monospecific mats of barnacles on the structures, some species of barnacle only associate with particular organisms (Jeffries and Voris 1996), with the latter not observable from imagery. Instead of barnacles, HA had a higher prevalence of macroalgae cover (up to 62% of quadrats possessed an undifferentiated form). Macroalgae genera could not be distinguished from imagery but was of low complexity/height. The presence of macroalgae on HA likely

limits space for barnacles to colonise. The ubiquity of two different colonising groups of benthic biota on two relatively close platforms may reflect varying processes of succession (linked to structure age), the presence of different predatory fish communities or even cleaning regimes.

Sun corals (*Tubastraea spp*) were reasonably ubiquitous (5–38% of quadrats) but present in low cover (< 6%) on HA and were not observed at all on GSP. Unlike other jackets that have been surveyed in Australia (> 50% cover of quadrats in McLean et al. 2019) and the Gulf of Mexico (Kolian et al. 2017; Sammarco et al. 2013), their cover was not extensive here where it was intermixed with soft corals and sponges. The two species observed are most likely to be *T. faulkneri* (orange sun coral) and *T. micranthus* (black sun coral), although formal identification is required. *T. faulkneri* is known from the Indo-Pacific Ocean and for producing a toxic compound that inhibits the settlement and growth of competitor corals (Koh and Sweatman 2000). *T. micranthus* naturally occurs in the Indian (Comores and Madagascar to the Fiji Islands) and Pacific Oceans. *T. micranthus* are now, however, widespread across the globe and significant invasive species in the Atlantic (Sammarco et al. 2013; Capel et al. 2019) where they appear particularly dominant on artificial structures while tending not to exhibit this same dominance on natural reefs (Sammarco et al. 2014). This is the third study on offshore platforms of north-west Australia that has documented the presence and abundance of *Tubastraea spp*. While they are present within their natural range here, further research is required to understand the distribution and extent of sun coral species on artificial and natural reefs in Australia and the ecological implications of anthropogenic impacts (climate change, artificial structures) on its distribution and abundance.

Sea fans (Melithaeidae sp1) were observed only on GSP but identification to genus level of this family is not possible without physical examination of the sclerites. Observed only in two quadrats, the 'tree-like' soft coral was light pink in appearance (Fig. 3E). The deep blue coloured soft coral, *Dendronephthya sp1* (Nephtheidae), was only observed on HA while *Carijoa sp1* (Alcyonaceae) was observed on both platforms. Each of the soft coral taxa observed occur in moderate to high current flow environments where they can filter feed on zooplankton and other food particles (e.g., phytoplankton) that come within reach. Research off the coast of Eilat, Israel, has shown that soft corals of the family Nephtheidae can be dominant on artificial reefs but not natural reefs, likely due to the vertical nature of the artificial structures exposing them to currents that can enhance their development (Perkol-Finkel and Benayahu 2004). A high diversity of benthic biota is known to exist in this offshore region (Richards and Rosser 2012; Fromont et al. 2016) and further targeted research is required to assess diversity on infrastructure present nearby. The benthic communities almost completely covering each of the platform structures would provide important shelter and food opportunities for a range of fauna species (e.g., van Lier et al. 2017).

In summary, the two relatively small platform structures surveyed here are within the BIMMA and possess marine communities that share species with those known to exist in surrounding natural ecosystems. The diversity of fish communities was high, although likely higher than that we were able to quantitatively assess using ROV video imagery. The platforms provide a unique habitat that a subset of fish species utilise to serve their specific ecological niche. While all species present on platforms occur in natural surrounding ecosystems, the platform structures facilitate their co-occurrence in a single place with

habitat spanning the water column from the surface to the seafloor. The significance of marine communities present on these, and other platform structures in this conservation significant region, requires investigation. This can occur by comparing communities present on platforms to those in natural ecosystems, both within and outside sanctuary zones (to better understand their role as *de facto* marine reserves). Further, and perhaps most importantly, research should examine the processes that facilitate species establishment and dispersal in addition to the movement of organisms between these structures and surrounding ecosystems – to understand the ecological role these structures play in the marine ecosystem. Lastly, the research demonstrates the value of science-industry partnerships where simple modifications to enhance industry ROVs can yield important scientific information of broad relevance to management and industry (Macreadie et al. 2018; McLean et al. 2020).

Declarations

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Conflicts of interest/competing interests

The authors have no conflicts of interest or competing interests with the research presented.

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Not available without consent from Santos Ltd.

Code availability

Not applicable

Authors' contributions

DM and MB together designed all aspects of the surveys, undertake statistical analysis and writing.

Ethics approval

Not applicable

Consent to participate

Not applicable

Consent for publication

Santos Ltd and the Australian Institute of Marine Science consent to publication in Marine Biology.

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Tables

Table 2 is not available with this version.

Figures

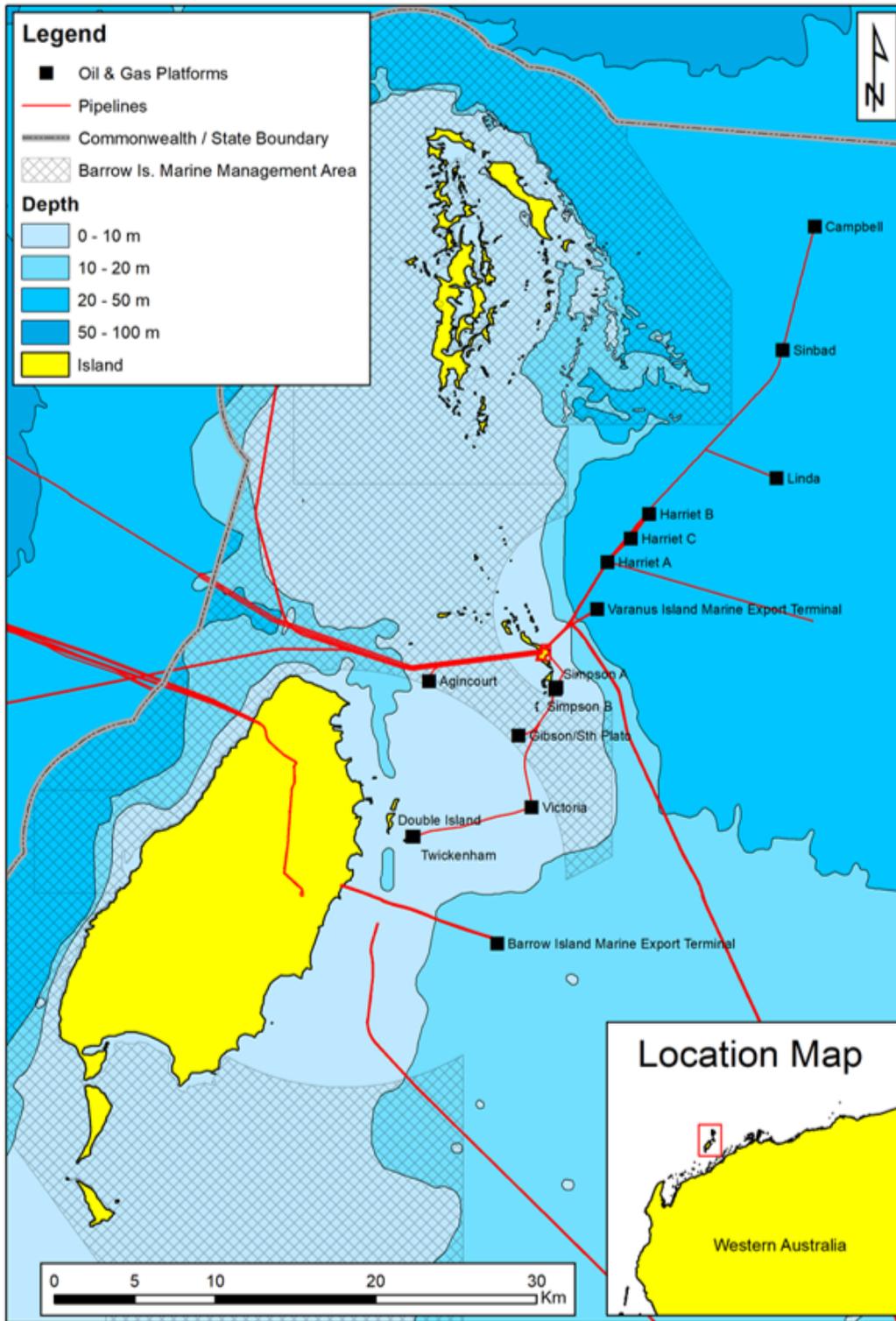


Figure 1

Location of oil and gas infrastructure surrounding the Lowendal Islands. Santos' platforms are indicated (including the two study sites Harriet A, Gibson/Sth Plato), in addition to subsea pipelines and the Barrow Island Marine Management Area.

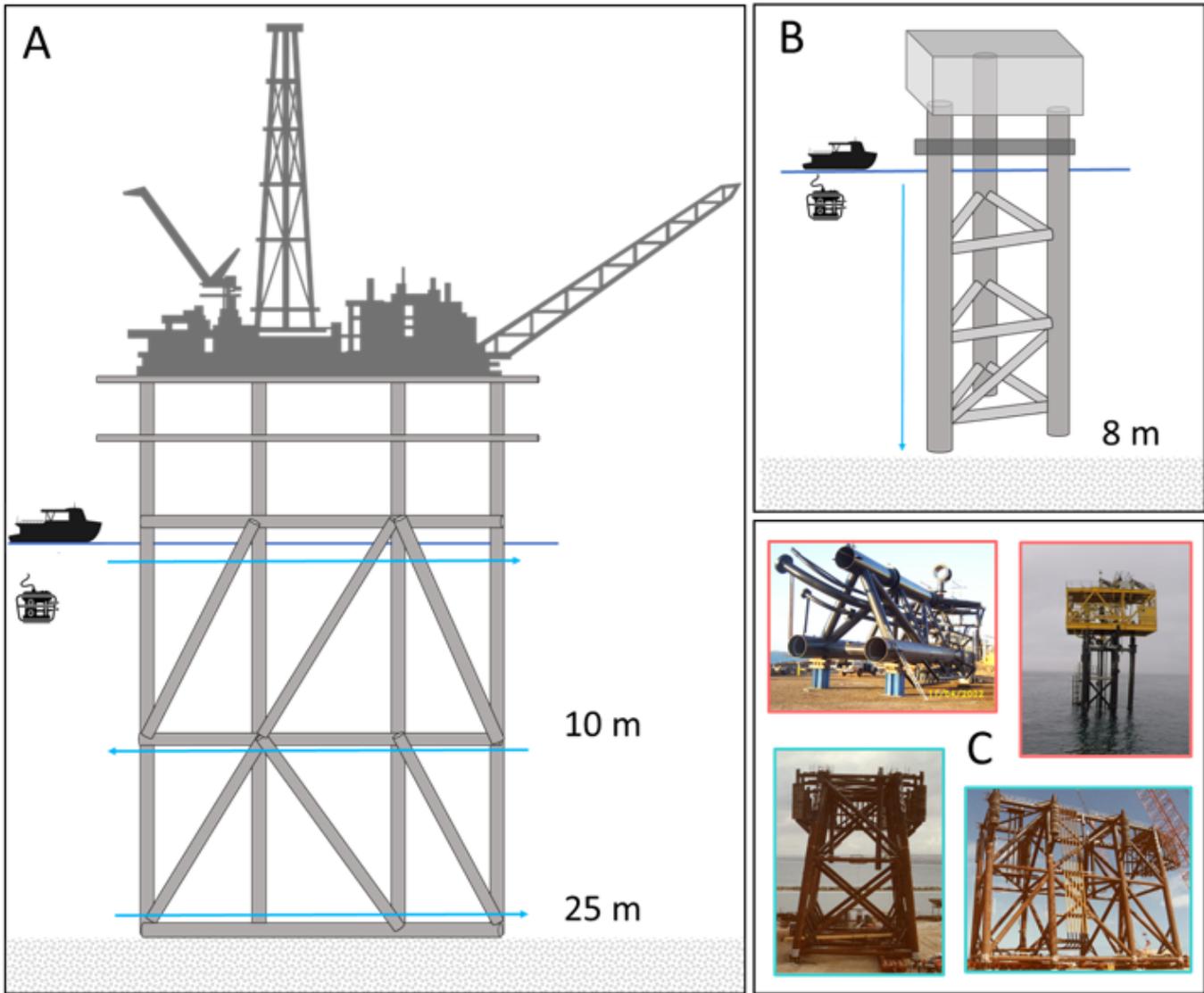


Figure 2

ROV surveys of marine communities at Harriet Alpha (A) and Gibson/South Plato (B) where blue arrows indicate the depths at which fish and benthic community surveys were undertaken. Panel C shows the structures as they appear above water with pink Gibson/South Plato and blue Harriet Alpha. Drawings are not to scale.

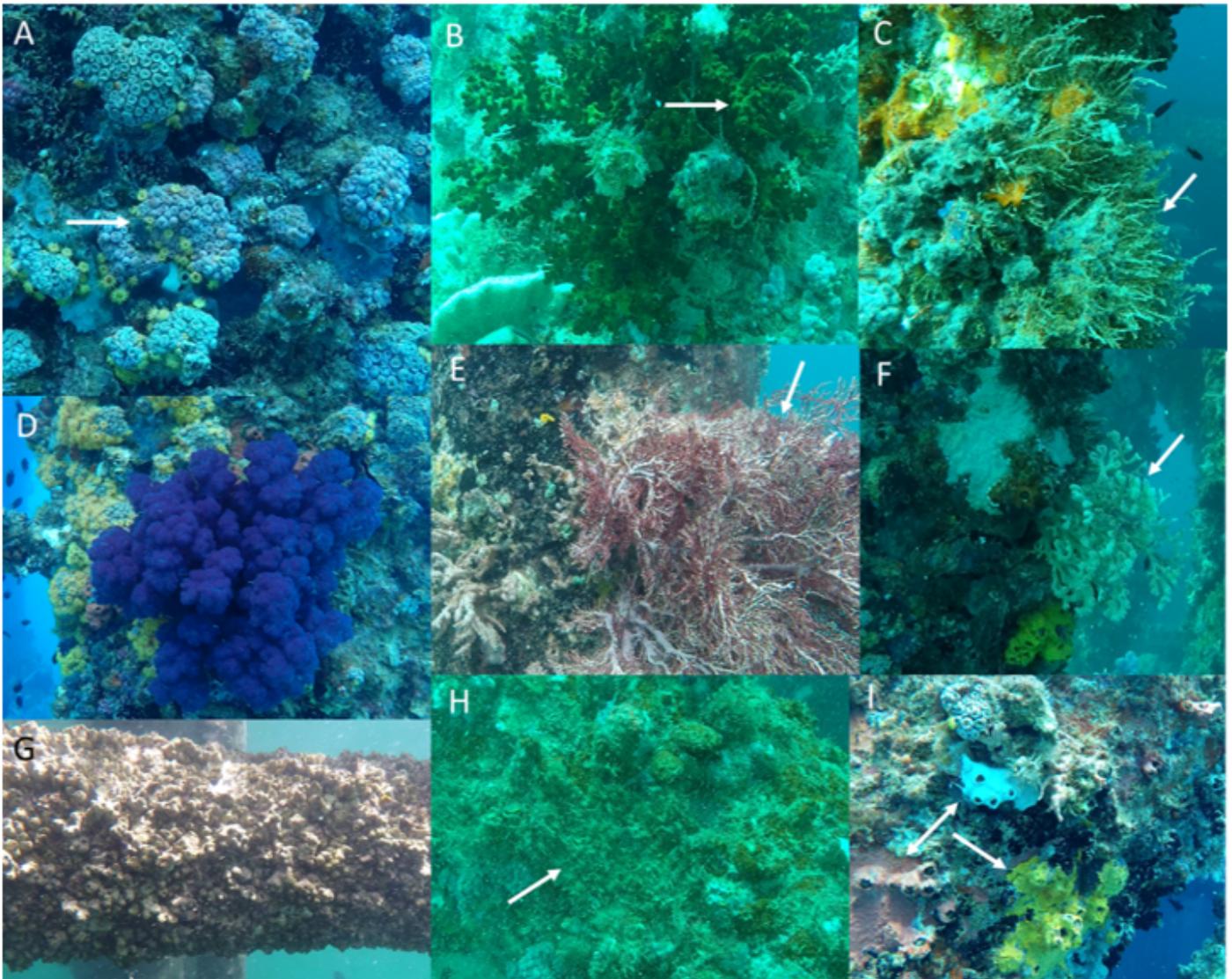


Figure 3

Examples of benthic biota observed on Harriet Alpha (HA) and Gibson/South Plato (GSP) platforms; A) *Tubastraea faulkneri* (orange cup coral); B) *Tubastrea micranthus* (black sun coral); C) *Carijoa* sp1 (soft coral); D) *Dendronephthya* sp1 (soft coral); E) *Melithaeidae* sp1 (sea fan); F) unidentified soft coral, likely *Alcyonacea*; G) barnacles (*Cirripedia*); H) unknown macroalgae; I) encrusting sponges (species unknown).

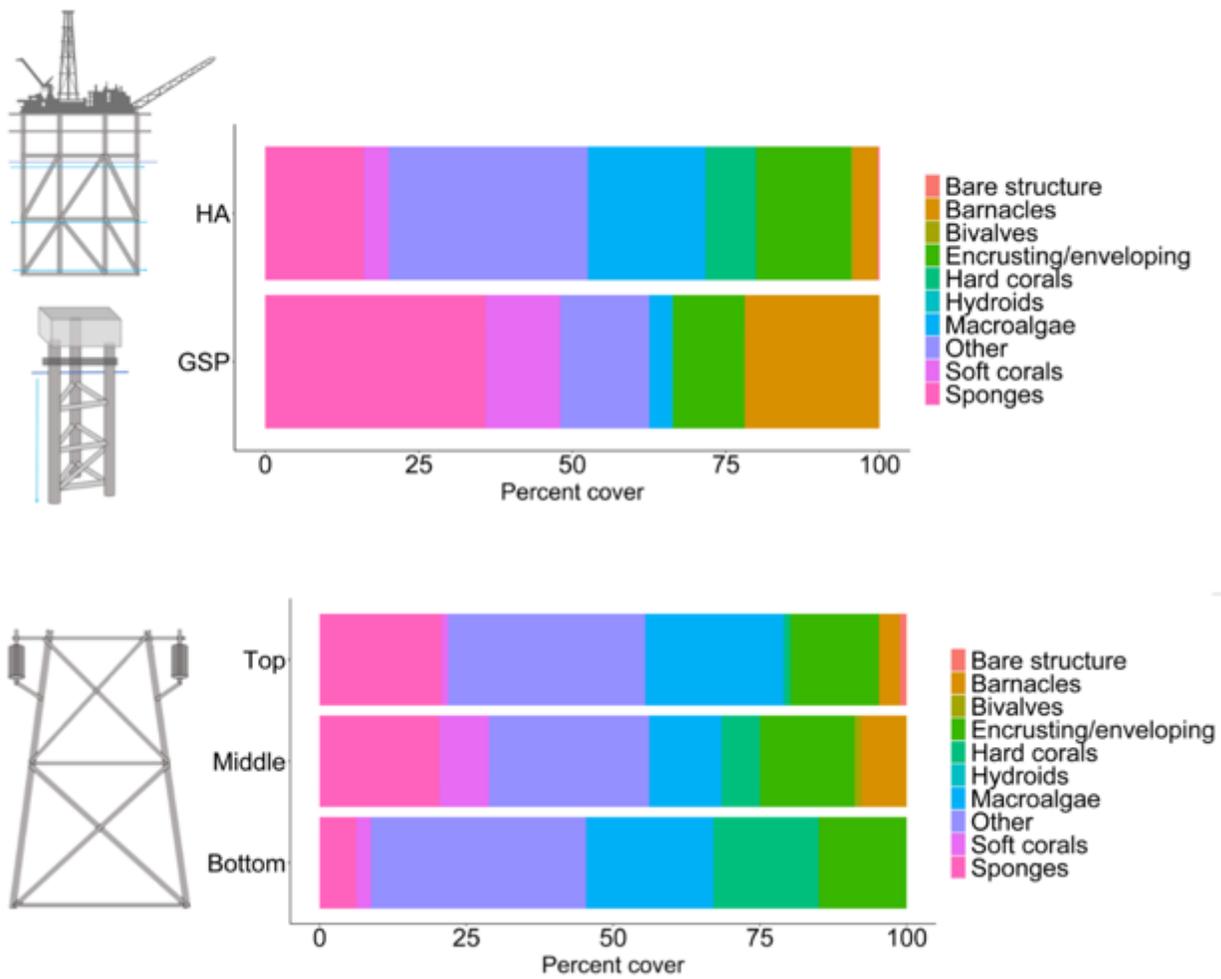


Figure 4

Percent cover of broad categories of benthic biota observed on A) Harriet Alpha (HA) and Gibson/South Plato (GSP) (top panel) and B) at the top, middle and bottom sections of Harriet Alpha (HA) (bottom panel).

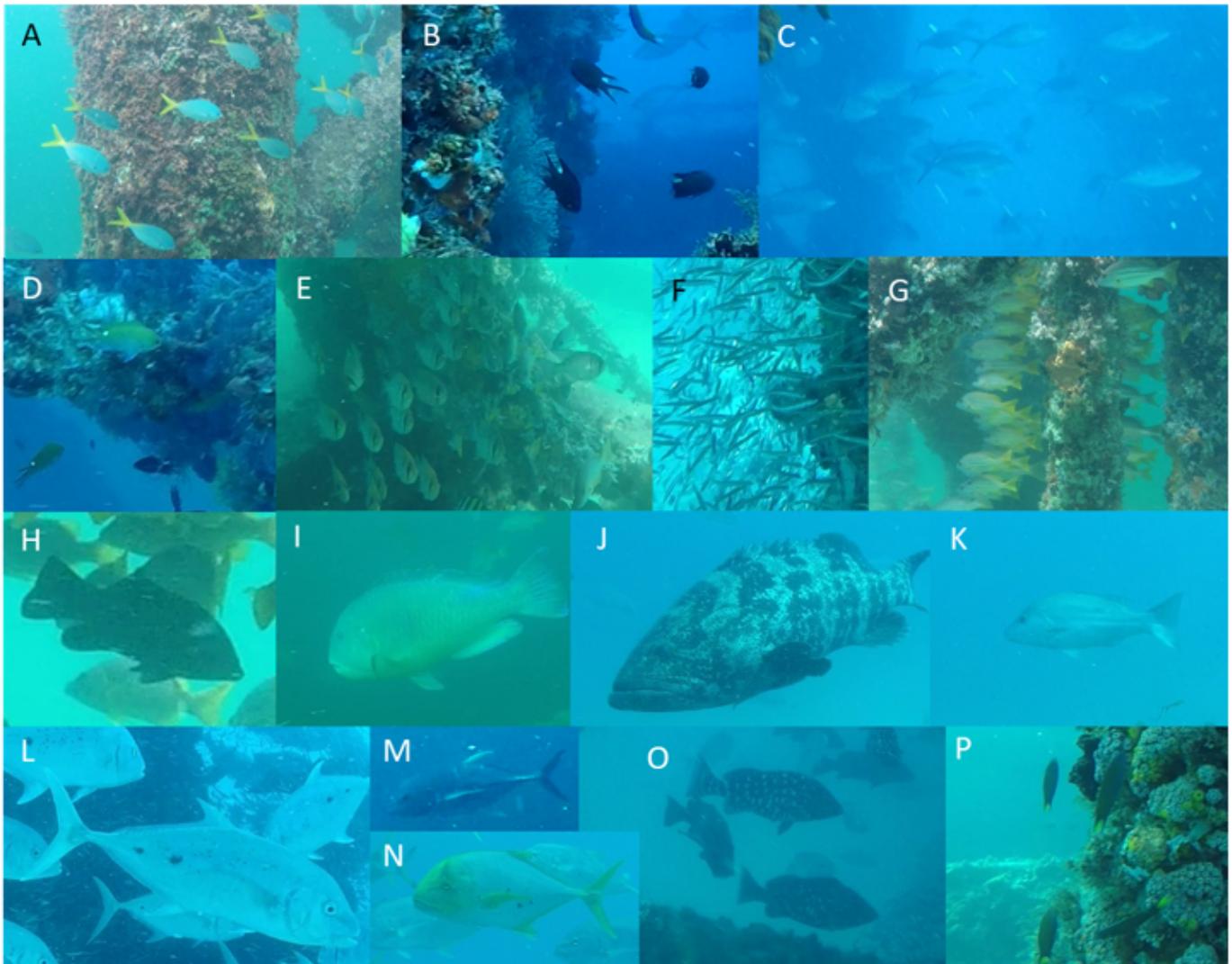


Figure 5

Abundant (A-G) and fishery target (H-O) species observed around HA and GSP; A) *Caesio cuning*, yellowtail fusilier, B) *Neopomacentrus cyanomos*, regal demoiselle, C) *Alepes vari*, herring scad, D) *Chromis fumea*, smoky puller, E) *Glaucosoma magnificum*, threadin pearl perch, F) baitfish, G) *Lutjanus carponotatus*, stripey snapper, H) *Psammoperca waigiensis*, Waigieu seaperch, I) *Choerodon schoenleinii*, blackspotted tuskfish, J) *Epinephelus coioides*, goldspotted rockcod, K) *Lutjanus russellii*, Moses' snapper L) *Carangoides fulvoguttatus*, turrum, M) *Caranx ignobilis*, giant trevally, N) *Gnathanodon speciosus*, golden trevally, O) *Thalassoma lunare* (moon wrasse).

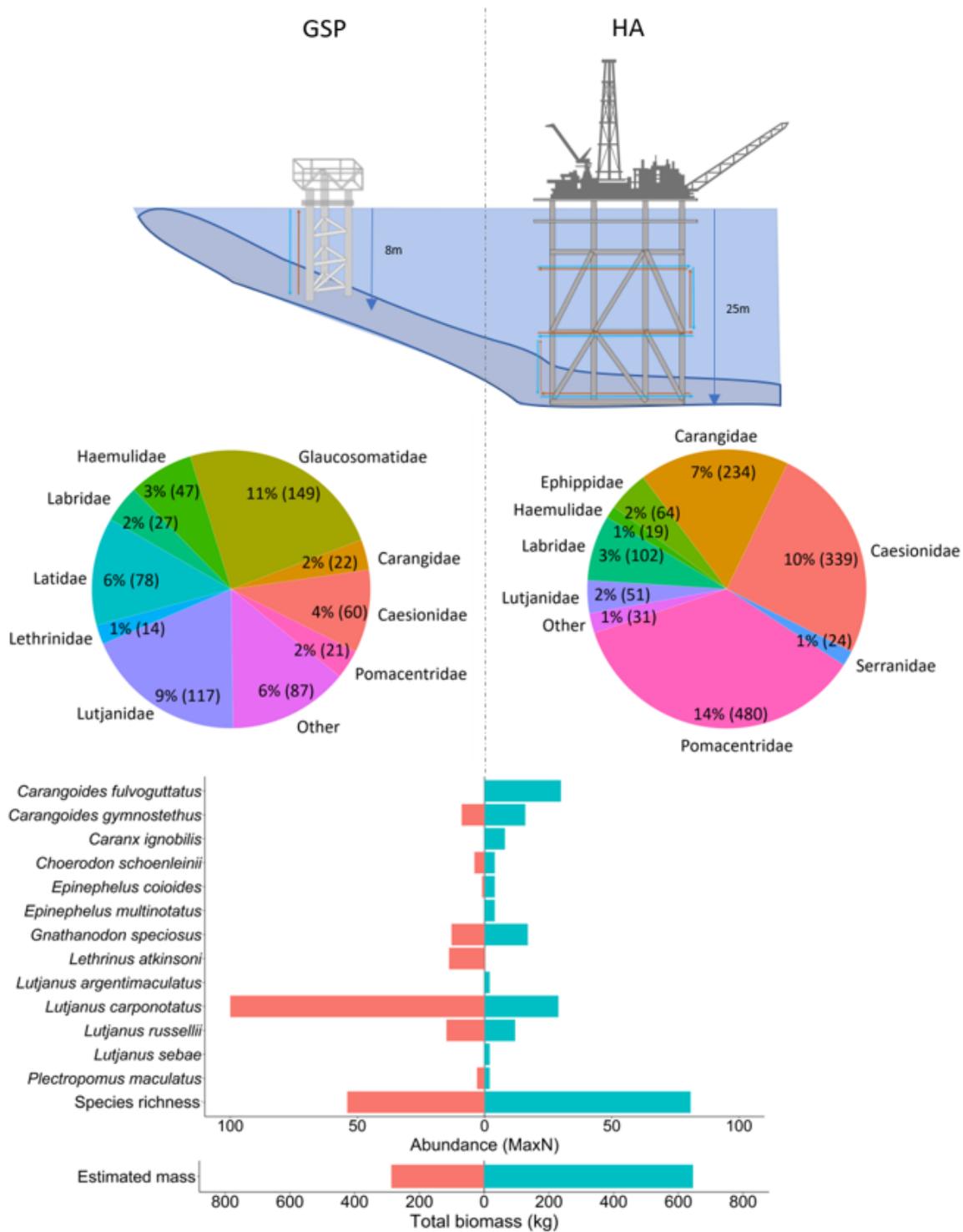


Figure 6

A comparison of the proportion of the fish assemblage within each family, of fish species richness, estimated biomass and of the abundance of fishery target species on Harriet Alpha (HA) and Gibson/South Plato (GSP) platforms.

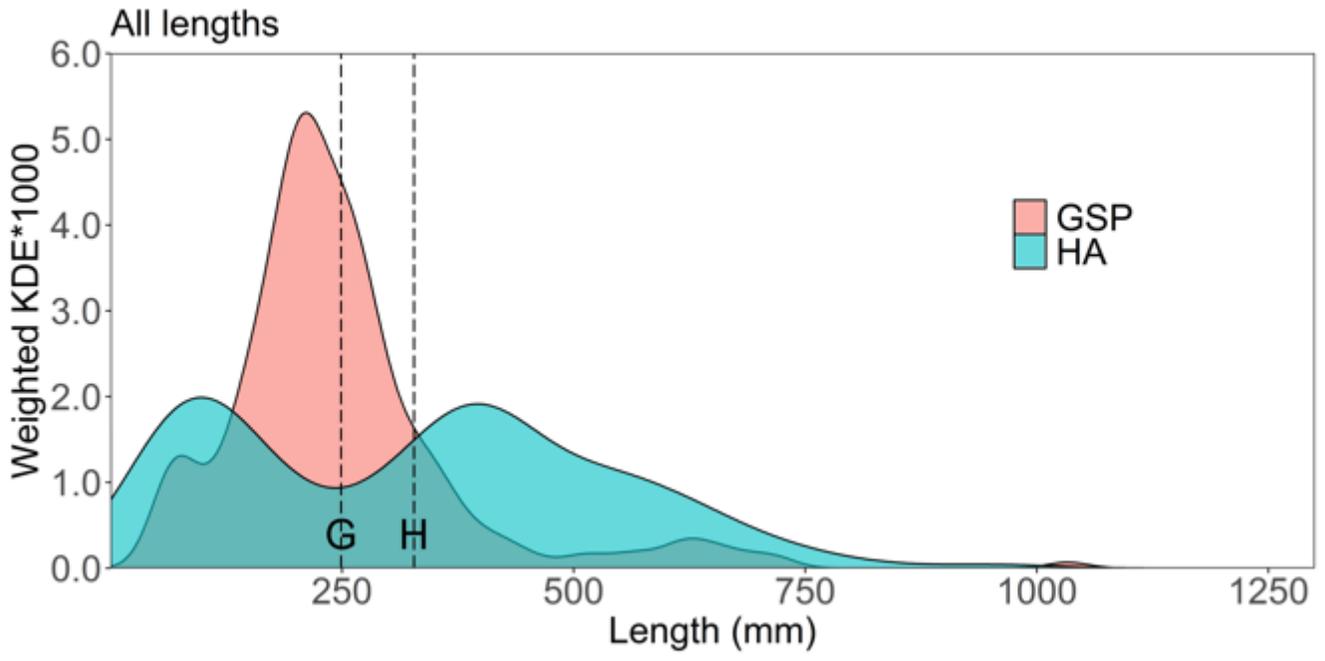


Figure 7

Length distribution (kernel density estimates) for all measured fish species that comprise MaxN estimates on GSP and HA platforms. Dashed lines represent the mean length for each distribution.

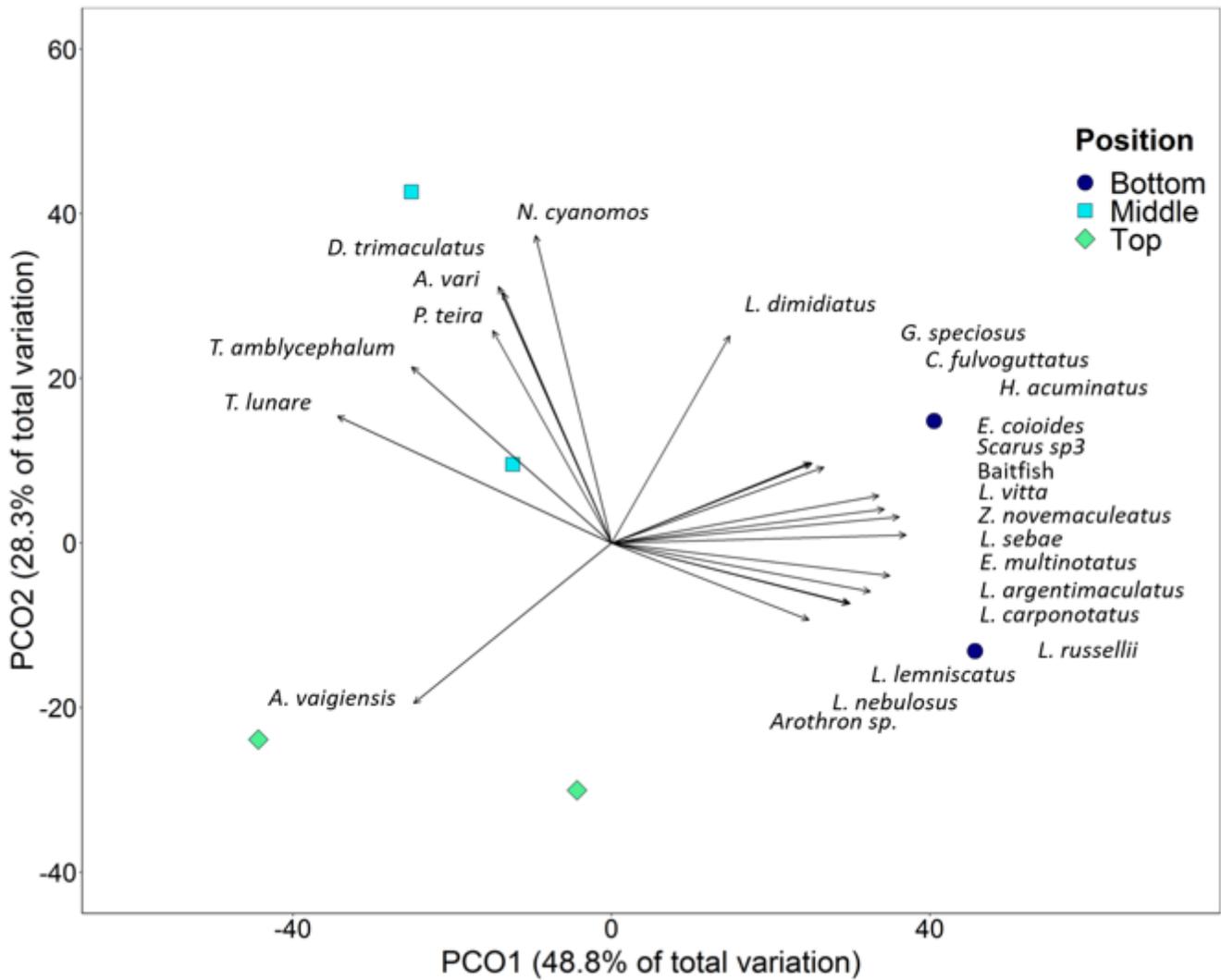


Figure 8

Principal Coordinates Analysis (PCO) of multivariate fish abundance at each transect surveyed at the bottom, middle and top of HA platform. Arrows represent fish species showing significant correlation ($|R| \geq 0.6$) with the PCO axes.

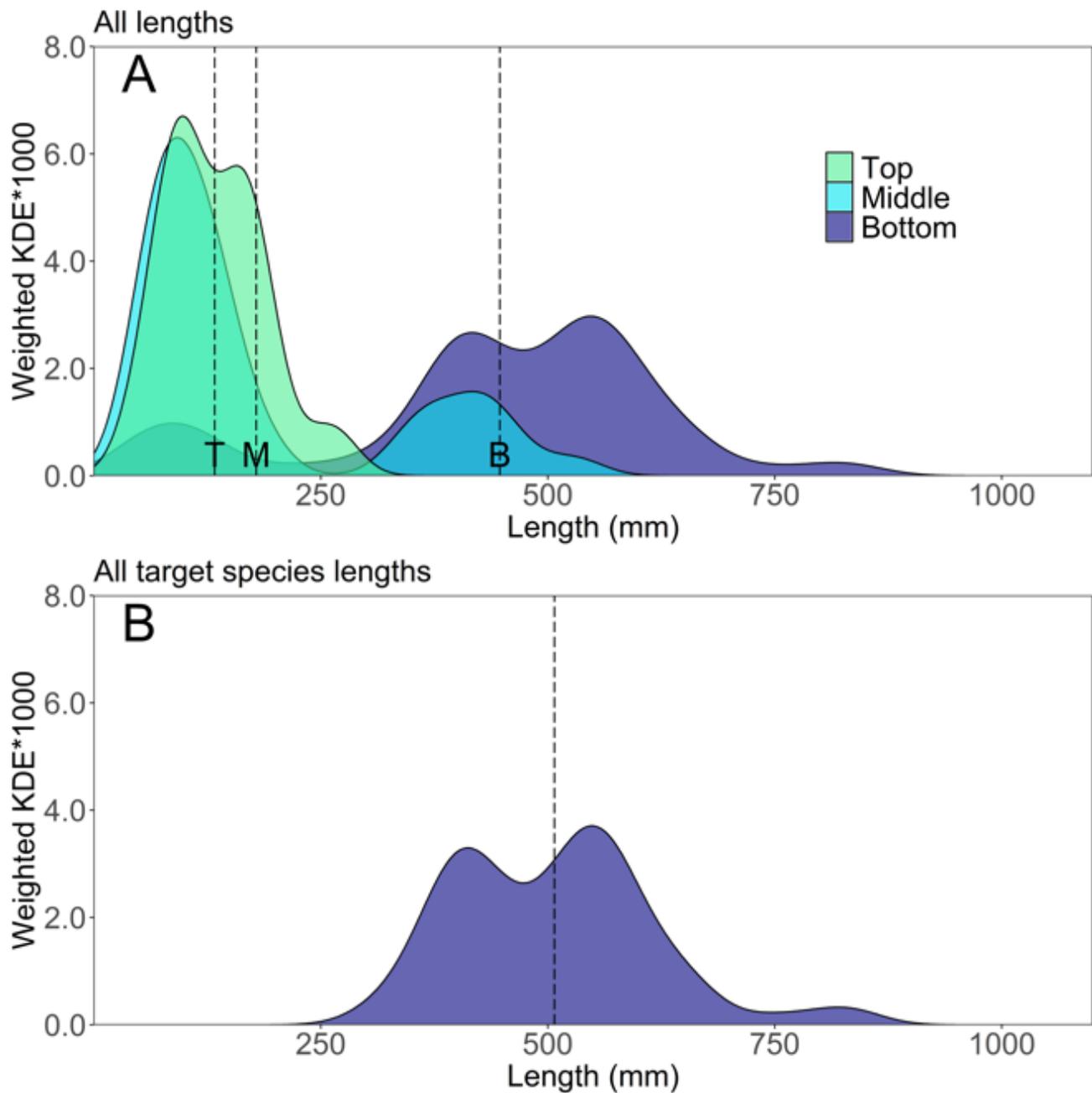


Figure 9

Length distribution (kernel density estimates) for all measured fish species on transects performed near the surface, at mid-water (10 m) and the seafloor (25 m) on HA platform. Dashed lines represent the mean length for each distribution.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [SupplementaryData.docx](#)