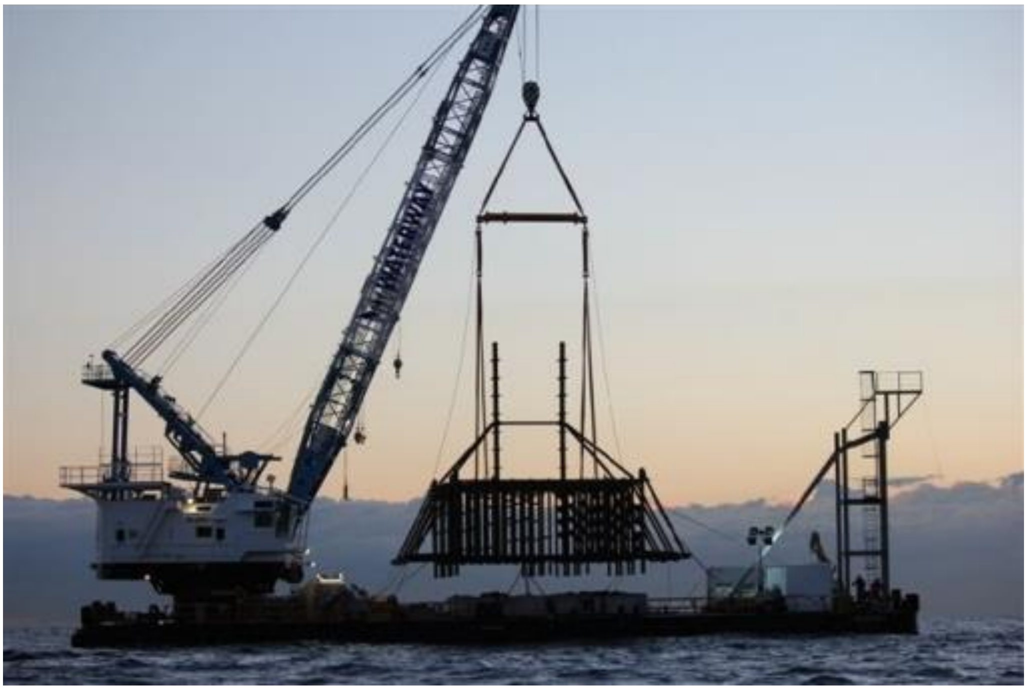
Sydney offshore artificial reef



Environmental Monitoring – Final Report

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More Information

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Non-Technical Summary

On the 12th of October 2011 the first purpose built offshore artificial reef (OAR) for New South Wales was dropped approximately 2 km south-east of South Head off Sydney Harbour. The Department of Primary Industries initiated a long term monitoring program to ensure the OAR had no significant adverse impacts on the marine environment and that the reef did not pose a danger to marine users. Fish assemblages were assessed using a variety of underwater camera methods including benthic baited cameras and towed cameras in the pelagic zone. Fish were found to rapidly colonise the OAR following its deployment and recruitment of new species continued rapidly during 2012 with a total of 49 species identified by the end of 2014. Yellow tail scad and mado were the most abundant species while recreationally important species such as kingfish, snapper and leatherjacket were also abundant during all years. The fish community showed inter-annual variation due to the continued recruitment of new species to the OAR over the monitoring period. The fish community at the OAR remained distinct from nearby natural control reefs which were also monitored for comparative purposes. Differences between natural and artificial reefs are common and can be attributed to a number of factors including positioning, size and materials used to construct reefs. Recreational fishing effort was monitored from shore based cameras and showed an increase in effort over time and also fewer anglers fishing the OAR during winter when weather conditions restrict trailer-boat fishing activities. Approximately 90 fish were tagged with acoustic transmitters and listening stations were placed both at the OAR and nearby natural reefs. There was evidence of connectivity between the OAR and natural reefs with many tagged fish, consisting of a number of species, found to regularly move between the two areas. Settlement plates positioned on the OAR showed a diverse range of invertebrates colonised the structure including ascidians, bryozoans and polychaetes.

1. Background

1.1 History of artificial reef development

The construction of artificial reefs in an effort to enhance fishing opportunities has a long history extending back to the 18th century. The construction and deployment of artificial reefs has been particularly prolific in South-East Asia , North America and more recently in Europe (Bohnsack and Sutherland 1985, Baine 2001). Artificial reefs were initially constructed from a wide variety of materials including car tyres, trams, aircraft, decommissioned ships and oil platforms among many more, and are collectively referred to as 'materials of opportunity' (Brickhill, Lee et al. 2005, Krohling, Brotto et al. 2006). These materials were cheap and readily available and often had a perceived added advantage of being a novel and environmentally beneficial way of dealing with unwanted waste (Pollard 1989).

Waste materials however, are not normally designed to persist in aquatic environments, and there is a history of the materials not only breaking down and therefore no longer providing the structure for which they were deployed, but also leaching pollutants into the surrounding waters (Kellison and Sedberry 1998, Collins, Jensen et al. 2002). Problems with early artificial reefs were further compounded by a lack of clear objectives and often little monitoring pre- and post reef deployment (Svane and Petersen 2001, Wilding and Sayer 2002). As such, the outcomes in terms of fisheries enhancement were difficult to determine. Ecological research of fish on natural reefs showed clear patterns of increasing fish diversity and abundance with increasing complexity of reef structure (Robertson and Sheldon 1979, Roberts and Ormond 1987) This led to a shift in the use of design specific materials which are structurally complex, including internal spaces, which did not pose any environmental risk and were often constructed from concrete or steel and are described as 'purpose built reefs' (Kellison and Sedberry 1998, Sherman, Gillian et al. 2002). Along with a shift in the actual design of reefs, came an increasing awareness of the importance of the location and configuration of the reef and clear objectives which could be evaluated with a rigorous monitoring program (Seaman 2000, Svane and Petersen 2001, Strelcheck, Cowan et al. 2005). It is now acknowledged that successful artificial reef projects should be able to demonstrate the project meets pre-deployment goals through the evaluation of ecological, physical and socio-economic variables (Folpp 2012). This includes making comparisons to nearby natural reef, control sites as well as suitable temporal 'before and after' monitoring (Fabi and Fiorentini 1994, Lowry, Glasby et al. 2014)

Initially, artificial reefs were primarily seen as fish aggregation structures, which would increase fishing revenue (Santos and Monteiro 2007). However it quickly became evident that simply attracting fish to a location only increases fishing efficiency and has no long term fisheries enhancement, due to local population loss. It was acknowledged for any artificial reef to have any real fisheries enhancement capability, it must increase local productivity in order to augment natural fish production and thereby support local fisheries (Osenberg, St Mary et al. 2002). The issue of 'attraction vs production' has remained prominent in the development of artificial reef design, management and evaluation to this day (Bohnsack 1989). There are now increasing signs, from rigorous scientific studies that artificial reefs which are well planned and implemented, do increase local productivity and enhance, rather than attract fish populations (Johnson, Barnett et al. 1994).

Within an Australian context, the development of artificial reefs follows a similar trend to that which has been observed on a global scale. Early reefs employed 'materials of opportunity', for example, car tyres were regularly used along coastlines which contained little natural structure such as Port Phillip Bay in Victoria and Gulf St Vincent and Spencer Gulf in South Australia (Pollard 1989, Branden, Pollard et al. 1994, McGlennon and Branden 1994). As awareness of the negative environmental impacts of waste material grew, deployments and research into artificial reefs stalled during the mid 1980's. Like in other parts of the world, deployments of artificial reefs was generally completed without any clearly defined goals or monitoring regimes, and so in addition, it was not possible to demonstrate these reefs were actually enhancing local fish productivity.

1.2 Recent initiatives for artificial reefs in NSW and the development of the Sydney offshore artificial reef

The introduction in NSW of recreational fishing licence fees in 2001 generated revenue for recreational fishing enhancement initiatives (Lowry, Folpp et al. 2010). In 2004 NSW DPI gained funding through this revenue for the deployment and monitoring of artificial reefs. Following a significant consultation process, a number of large estuaries along the NSW coast were chosen as sites for the new reefs (Lowry, Folpp et al. 2010). These systems had recently been declared recreational fishing havens, where commercial fishing was no longer permitted. Clear qualitative objectives for the program were outlined and were complimented by a number of quantitative measures which were closely monitored, including fish abundance, size and community composition, as well as changes in the benthic community. The monitoring program itself consisted of a combination of baited remote underwater video (BRUV) and dive surveys of the fish community, photographic surveys of the benthic community and independent angling surveys to determine the utility of the reef (Lowry, Folpp et al. 2010). Surveys were undertaken prior to the deployment of the reef and included comparisons with nearby natural reef and bare sand habitat. The reefs consisted of Mini-Bay Reef Balls® and were deployed at sites specifically selected following a mapping exercise to identify the most suitable locations. The well planned and conducted approach taken to the deployment of artificial reefs in NSW estuaries was able to demonstrate the benefit of these reefs through sustained recruitment of species which were highly regarded among recreational anglers (Lowry, Glasby et al. 2014). This four year program set the foundation for future approaches in the planning, construction and evaluation of ecological, physical and socio-economic factors of artificial reef systems.

Following the success of the estuarine artificial reef program, NSW DPI began planning the deployment of an offshore artificial reef (OAR) which was recognised by the Ministers Advisory Council for Recreational Fishing (ACoRF) and the recreational fishing community as a high priority. Funding was secured from the Recreational Fishing Saltwater Expenditure Committee to investigate the potential for the establishment of three OARs along the NSW coast in shallow waters accessible by trailer-boat recreational anglers.

Sea Dumping Permits ensure that appropriate sites are selected, materials are suitable and appropriately prepared, that there are no significant adverse impacts on the marine environment and that the reef does not pose a danger to marine users. A condition of the Permit is that the Proponent (Trade and Investment) implement the proposed Environmental Monitoring and Management Plan (EMMP) submitted in September 2011.

The purpose of this report is to comply with annual reporting commitments associated with the EMMP (EPBC 2008/4176 section e [i & ii]) and associated Sea Dumping permit (SD2008/882).

2. Offshore artificial reef design and installation

The offshore artificial reef (OAR) unit design is 12 m x 15 m x 12 m (height x length x width) with the bulk of the internal structure in the lower 4 m (Figure 1). The OAR unit is manufactured from square hollow sections (SHS) and rectangular hollow sections (RHS) and plates, and weighs approximately 42 tonnes (dry weight). Four concrete anchor bocks are connected to each corner to ensure OAR stability.

The OAR unit has design certification to withstand a 1/100 year storm event (a wave height of approximately 18 m – HMax) and will have an operational lifespan of 30 years. The deployment site is approximately 1.9 km (1.3 nm) south-east of South Head (Sydney Harbour) at a depth of 38 m.

The OAR was lowered into position on the morning of 12 October 2011 (Figure 2), this was followed by the attachment of moorings and inspection by divers prior to commissioning on the 13 October 2011.

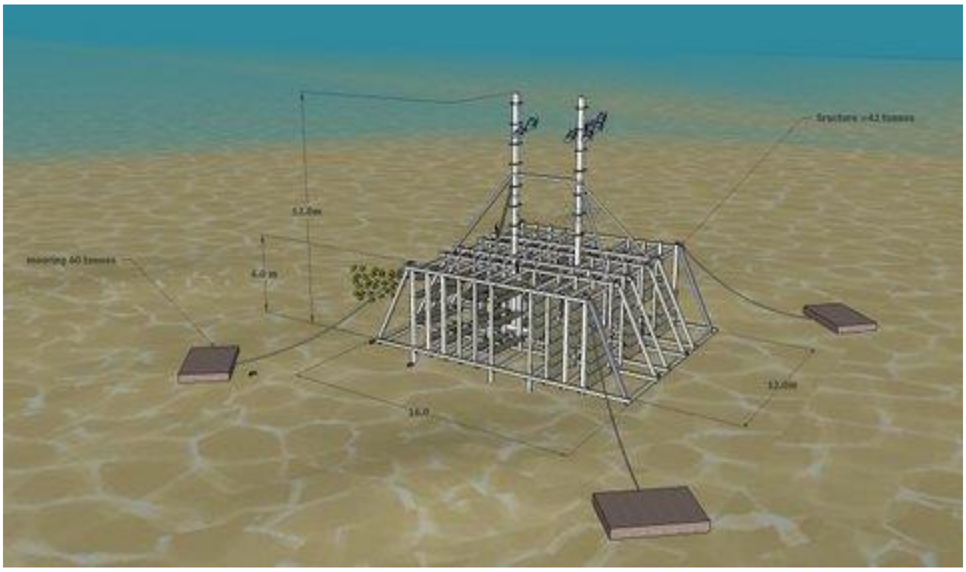

Figure 1 Dimensions of the Sydney Offshore Artificial Reef

3. Monitoring objectives

Monitoring objectives are broadly characterised as 'Priority One' and 'Priority Two'. Priority one monitoring objectives were mandatory under approval conditions. Priority two objectives were to be addressed given available funding and resources.

3.1 Priority one objectives

Priority One objectives relate to the species composition and residency times of the fish community associated with the OAR, particularly in relation to how this differs to the fish assemblage associated with natural (control) reefs in the immediate vicinity. Additional priorities include an assessment of the level of interaction between threatened species and the OAR, structural integrity of the OAR, and the popularity of the OAR with recreational fishing groups.

3.2 Priority two objectives

Priority two objectives incorporate the assessment of benthic assemblages (soft sediments) including concentration of heavy metals, potential 'halo' effects around the OAR and an examination of the macroinvertebrate communities (including invasive and pest species) associated with the OAR. Additional priorities examine the potential for patterns of water movement associated with the OAR to affect local levels of productivity.

Figure 2 Deploying the offshore artificial reef

4. Materials and Methods

4.1 Methods used to meet Priority one objectives

4.1.1 Benthic and pelagic fish monitoring

Between 2011 – 2014 the finfish community (species diversity and abundance) associated with the OAR was survey using two methods; a stereo Baited Remote Under Video (BRUV) was deployed to assess the benthic fish community, while a towed 'Seaviewer' attached with a GoPro was used to assess the pelagic community around the OAR towers. The BRUV systems consisted of a stainless steel frame with two video cameras mounted inside submersible housings. The two cameras created stereo footage, allowing for length measurements of fish using the '*Event Measure'* software. A bait arm was attached to the frame which supported a bait container that contained sufficient bait (pilchards) to last the 30 minute deployments. BRUV surveys were conducted on a monthly basis with the equipment being deployed on the benthos adjacent to the OAR. In addition to the OAR, three other proximal natural 'control' reefs (Bondi, Dunbar and North Head) were also sampled on the same day using the same methods and equipment. A total of 119 BRUV deployments were made at the four sites between 2011 and 2014.

The Seaviewer was lowered to the depths of the two towers which form the upper structural sections of the OAR on the same days benthic BRUV deployments were conducted. Once a clear view of the towers was obtained, the Seaviewer was retrieved. During 2013-2014, 48 deployments of the Seaviewer were undertaken at the OAR. Relative abundance of fish species in both BRUV and pelagic footage was calculated using MaxN (Cappo, Speare et al. 2004, Cappo, De'ath et al. 2007). The lengths of fish which formed the MaxN estimates were also measured within the BRUV footage collected during 2013-2014.

Figure 3 Fiddler rays and leatherjacket viewed in a BRUV deployment at the OAR

Patterns in assemblage data generated from the BRUV deployments were explored visually using Primer 6. Data was square root transformed to reduce the influence of highly abundant species such as *Atypichthys strigatus* (mado) and *Trachurus novaezelandiae* (yellow tail scad). A Bray-Curtis dissimilarity matrix was constructed from which non-parametric MDS was used to observe patterns in the dataset. Species which were contributing towards the observed dissimilarity patterns among the sites were identified using the 'SIMPER' function.

Figure 4 Kingfish school around the towers of the OAR in footage taken with the Seaviewer GoPro

Length measurements of fish from the stereo BRUV footage were taken from deployments made at all sites during 2013 and 2014. Comparison between the mean lengths of the 12 species most common to all sites during both years was assessed.

In addition to the BRUV and Seaviewer deployments, fish assemblages around the OAR were further assessed in a dedicated sampling program using Rapid Unbaited Drop cameras (RUDs). The RUD consisted of two GoPro cameras attached to a stainless steel housing that were oriented to point in opposite directions, thereby covering close to a 360° view (Figure 5). The RUDs were dropped from the surface and once on the bottom, left for 5 seconds before being retrieved, providing a snapshot of the fish both on the substrate and up through the water column. A total of 360 drops were made around the OAR and out to a distance of 150 m away from the structure so abundances of fish relative to their distance from the OAR could be determined during 2013-2014. Abundance of fish observed in RUDs was measured using the MaxN method.

Figure 5 Design of the Rapid Unbaited Drop (RUD) camera, consisting of two opposite facing GoPro cameras

4.1.2 Annual Angler Effort and Harvest

Angler activity around the OAR was monitored using shore based cameras. Two cameras provided continuous footage, one directed at the OAR and a second directed at a reference location just offshore of North Head since 2011. To compliment data collected on angler activity at the OAR, trailer boat surveys at three survey areas around Sydney were conducted to assess the harvest levels of fish. Fish species were grouped into categories consisting of 'Elasmobranchs', 'Pelagics', 'Large Reef Fish', 'Herbivorous/Small Reef Fish' and 'Demersal Fish' which reflect the basic biology and ecology of recreationally important fish species.

4.1.3 Residency Times of Acoustically Tagged Fish

Investigation into the residency time of fish associated with the OAR and connectivity with the OAR and proximal areas of natural reef was quantified using ultrasonic telemetry. In total 84 fish consisting of 8 species captured from around the OAR and nearby natural reefs were implanted with ultrasonic transmitters (Table 1). These fish were then detected on an array of VR2 and VR4 receivers strategically located on the OAR and surrounding natural reef, providing a detailed understanding of movement and activity patterns of these fish.

Table 1 Species and tagging location of fish implanted with ultrasonic transmitters

Totals	OAR	Natural reef	Total
Banjo ray	9	1	**10**
Port Jackson shark	9	8	**17**
Eastern blue-spotted flathead	22	10	**32**
Blind shark	0	15	**15**
Snapper	0	6	**6**
Six-spine leatherjacket	0	3	**3**
Blue morwong	0	1	**1**
Total	40	35	**84**

4.2 Methods used to meet Priority Two objectives

4.2.1 Settlement plates

Invertebrate species which colonise the structure of the OAR were assessed by attaching settlement plates. These were deployed inside fish-exclusion cages and also included no-cage controls. Settlement plates were deployed, removed and redeployed over a 6 month cycle. Observations of the settlement plates were made using underwater video. This allowed not only the invertebrate community which colonise the structure to be assessed, but also the interaction between these invertebrates and fish through grazing.

5. Key Findings

5.1. Priority One Objectives

5.1.1 Benthic and Pelagic Fish Assemblages

Over the four years, 49 fish species were identified in the benthic BRUV footage at the OAR (

Table 3), a total of 90 species were recorded when data is pooled across the four sites with many species being unique to a particular reef, but found in low abundances. At the OAR, species richness increased from 13 fish species in 2011 to 30 species during 2014. At the control sites over the four years, 54 species were observed at Bondi, 57 at Dunbar and 51 species at North Head. With the exception of Bondi, species richness at the control sites remained relatively consistent over the four years (Table 2). Simpsons Index of Diversity was lowest each year at the OAR in comparison to each of the control sites, while North Head had the highest, except for 2012 when biodiversity was greatest at Bondi. *Trachurus novaezelandiae* had the highest relative abundance (MaxN) on the OAR in the first year after its deployment (Figure 8). Similar relative abundances of this species were observed during 2012, however abundances greatly increased during 2013 and 2014. Other species which were common around the OAR between 2012 and 2014 included new species such as *A. strigatus* and *Nelusetta ayraud* (ocean leatherjacket).

Table 2 Species richness and Simpsons Index of Diversity at the OAR and control sites between 2011-2014

Species Richness	**2011**	**2012**	**2013**	**2014**
OAR	13	24	27	30
Bondi	16	33	32	35
Dunbar	27	35	34	35
North Head	24	23	31	29
Simpsons Index of Diversity				
OAR	0.31	0.75	0.48	0.57
Bondi	0.89	0.92	0.87	0.79
Dunbar	0.78	0.77	0.80	0.78
North Head	0.95	0.91	0.91	0.92

Figure 6 Fish schooling around the offshore artificial reef

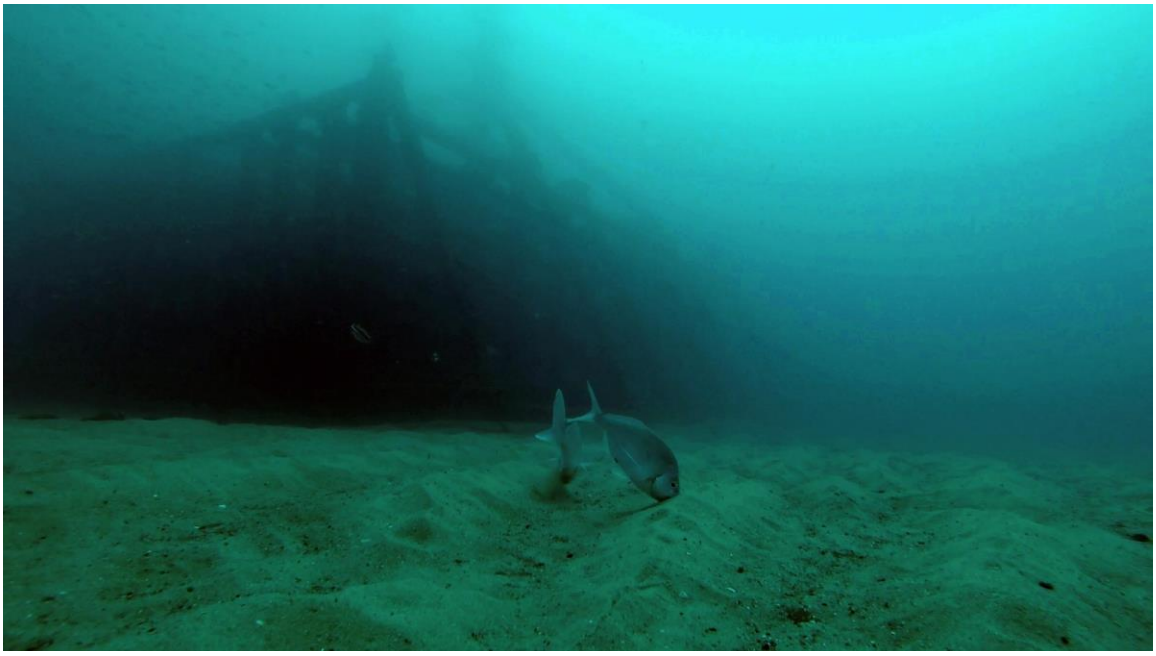

Figure 7 Reef associated blue morwong foraging the soft sediment around the OAR

Table 3 List of species identified in BRUV and Seaviewer footage at the OAR between 2011-2014

Pseudocaranx dentex	*Meuschenia trachylepis*
Trachurus novaezelandiae	*Nemadactylus douglasii*
Nemadactylus valenciennesi	*Dinolestes lewini*
Meuschenia freycineti	*Meuschenia flavolineata*
Meuschenia scaber	*Cheilodactylus fuscus*
Nelusetta ayraud	*Ophthalmolepis lineolatus*
Pseudocaranx	*Scobinichthys granulatus*
Platycephalus sp1	*Scorpis lineolata*
Trygonorrhina fasciata	*Nelusetta ayraudi*
Scorpaena jacksoniensis	*Eubalichthys mosaicus*
Upeneichthys lineatus	*Myliobatis australis*
Platycephalus caeruleopunctatus	*Chaetodon guentheri*
Anoplocapros inermis	*Orectolobus ornatus*
Acanthopagrus australis	*Nemadactylus douglasi*
Pagrus auratus	*Enoplosus armatus*
Heterodontus portusjacksoni	*Pseudocaranx georgianus*
Gymnothorax prasinus	*Parma microlepis*
Atypichthys strigatus	*Cheilodactylus vestitus*
Microcanthus strigatus	*Coris picta*
Dasyatis brevicaudata	*Paracaesio xanthura*
Seriola lalandi	*Plotosus lineatus*
Parupeneus spilurus	*Hypoplectrodes maccullochi*
Zeus faber	*Rhabdosargus sarba*
Orectolobus maculatus	*Canthigaster callisterna*
Aulopus purpurissatus	

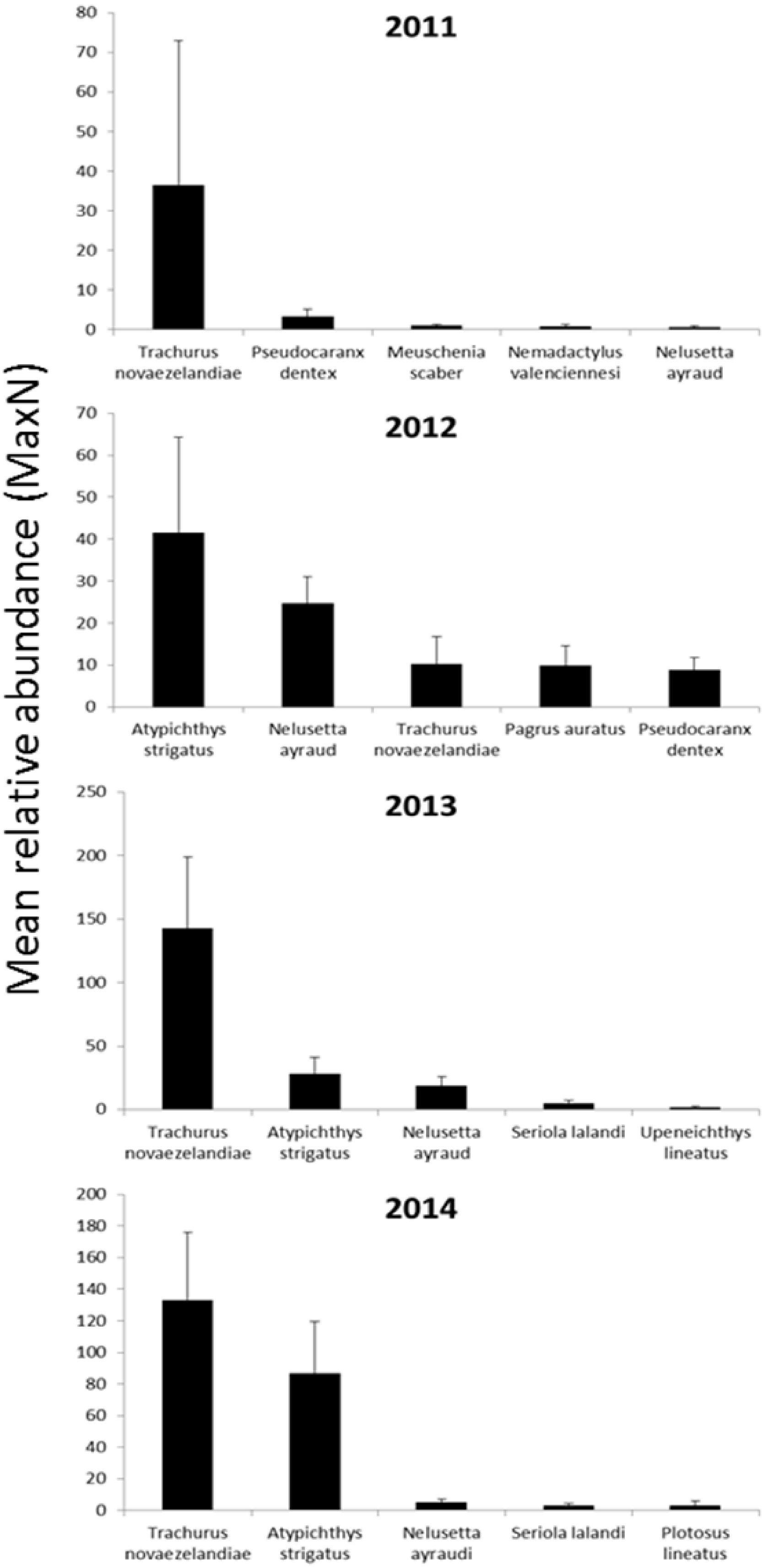

Figure 8 Mean relative abundance (MaxN) of the five most common species at the OAR between 2011-2014 (± S.E.)

MDS ordinations allow for patterns in communities to be evaluated with points positioned closer together on the plot representing samples which have similar fish communities and points spread further apart, having divergent communities. Patterns in the fish community at the OAR show it was distinct from the three control sites at Bondi, Dunbar Reef and North Head each year between 2011 and 2014 (Figure 9). Of the control sites, overlap of samples from Bondi and North Head indicate they had similar fish communities. Dunbar Reef appeared to differ from the other two control sites, particularly between 2012 and 2014 (Figure 9). The SIMPER analysis indicated that yellow tail scad were mostly responsible for dissimilarity in the fish community between the OAR and control sites during 2013 and 2014 and also had an effect during 2011 (Table 4). *Atypichthys strigatus* were also responsible for much of the dissimilarity between 2012 -2014, while bull rays (*Myliobatis australis*) were identified as influential in the dissimilarity between the OAR and control sites during 2012 and 2013.

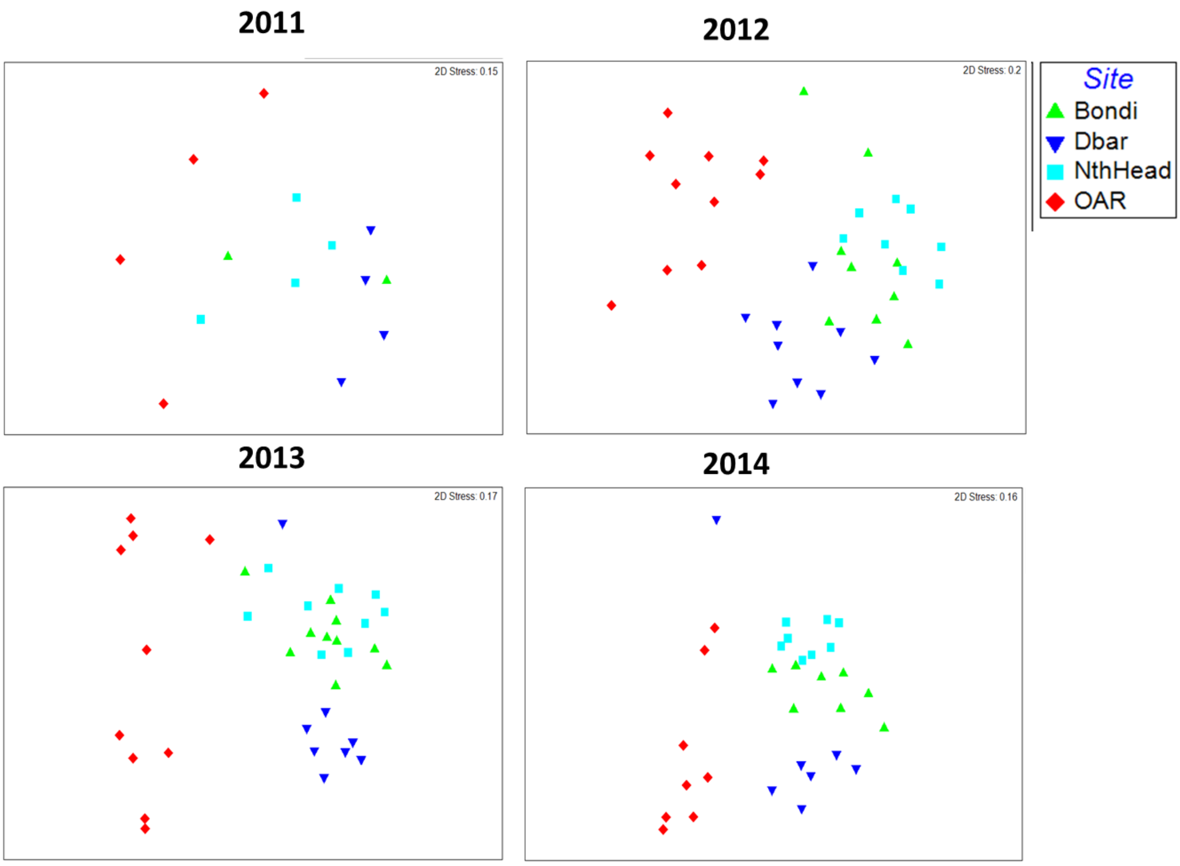

Figure 9 Non-metric MDS ordinations of the fish assemblages (MaxN) at the OAR and control sites between 2011-2014

When data across months was pooled and the centroids for each site during each year plotted, it was evident that there was greater inter-annular changes in fish assemblages at the OAR compared to the three control sites, which remained relatively consistent in comparison (Figure 10).

Table 4 Percentage contribution of the top three species to the dissimilarity between the OAR and the three control sites (Bondi, Dunbar and North Head) between 2011 – 2014

Species	Av.Diss	% Contrib (S.D.)	Species	Av.Diss	% Contrib (S.D.)	Species	Av.Diss	% Contrib (S.D.)	Species	Av.Diss	% Contrib (S.D.)
	2011	2011		2012	2012		2013	2013		2014	2014
OAR - Bondi			**OAR - Bondi**			**OAR - Bondi**			**OAR - Bondi**		
Ophthalmolepis lineolatus	11.45	**11.99 (1.64)**	*Myliobatis australis*	12.92	**15.44 (1.6)**	*Trachurus novaezelandiae*	18.02	**20.95 (1.02)**	*Trachurus novaezelandiae*	18.13	**20.95 (1.51)**
Trachurus novaezelandiae	9.69	**10.15 (0.52)**	*Atypichthys strigatus*	8.8	**10.52 (0.67)**	*Myliobatis australis*	8.8	**10.23 (0.87)**	*Atypichthys strigatus*	13.29	**15.36 (1.3)**
Meuschenia trachylepis	8.09	**8.48 (1.64)**	*Pseudocaranx dentex*	6.09	**7.28 (1.29)**	*Ophthalmolepis lineolatus*	6.46	**7.51 (2.55)**	*Ophthalmolepis lineolatus*	5.39	**6.23 (2.53)**
OAR - Dunbar			**OAR - Dunbar**			**OAR - Dunbar**			**OAR - Dunbar**		
Atypichthys strigatus	19.85	**21.03 (1.17)**	*Atypichthys strigatus*	10.85	**13.24 (1.39)**	*Trachurus novaezelandiae*	16.83	**19.12 (1)**	*Trachurus novaezelandiae*	18.67	**21.47 (1.37)**
Ophthalmolepis lineolatus	8.36	**8.86 (2.17)**	*Myliobatis australis*	10.66	**13.02 (1.81)**	*Atypichthys strigatus*	10.11	**11.49 (1.67)**	*Atypichthys strigatus*	13.67	**15.72 (1.2)**
Trachurus novaezelandiae	7.6	**8.05 (0.55)**	*Chromis hypsilepis*	6.26	**7.64 (0.59)**	*Myliobatis australis*	8.08	**9.18 (0.84)**	*Seriola lalandi*	5.04	**5.79 (0.61)**
OAR - North Head			**OAR - North Head**			**OAR - North Head**			**OAR - North Head**		
Trachurus novaezelandiae	9.53	**10.25 (0.54)**	*Myliobatis australis*	14.53	**16.69 (1.79)**	*Trachurus novaezelandiae*	20.41	**23.42 (1)**	*Trachurus novaezelandiae*	21.19	**24.09 (1.54)**
Pagrus auratus	8.58	**9.24 (1.51)**	*Atypichthys strigatus*	9.76	**11.22 (0.69)**	*Myliobatis australis*	10.6	**12.17 (0.83)**	*Atypichthys strigatus*	15.91	**18.09 (1.22)**
Pseudocaranx dentex	6.61	**7.12 (0.94)**	*Pseudocaranx dentex*	7.18	**8.25 (1.26)**	*Atypichthys strigatus*	6.53	**7.49 (0.79)**	*Nelusetta ayraud*	5.49	**6.24 (1.13)**

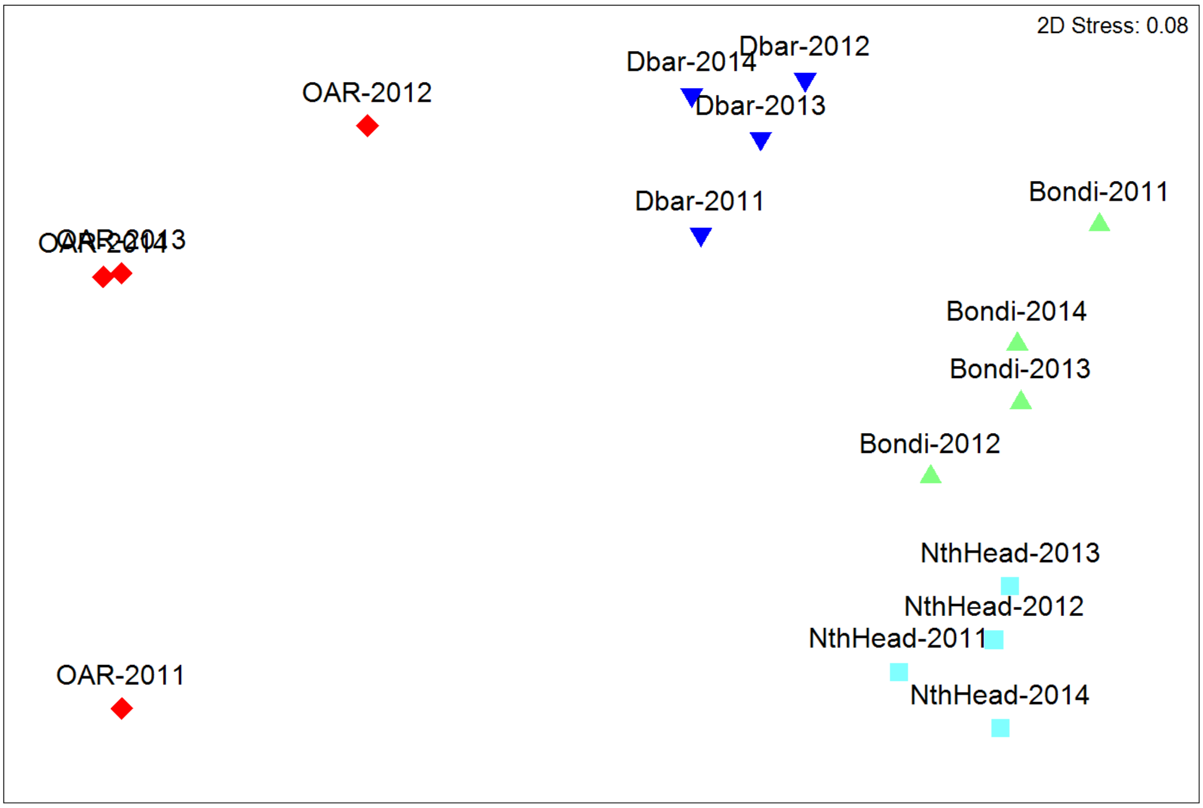

Figure 10 MDS ordination of annual centroids at the OAR and three control sites between 2011 – 2014

The largest species recorded at the OAR was *Heterodontus portjacksoni* (Port Jackson shark). Mean length of this species during 2013 and 2014 at the OAR were comparable to the three control sites (Figure 11). Of the other species common to all four sites, lengths did not differ greatly among these sites, an exception was *Seriola lalandi* (yellow tail kingfish) which during 2014, larger individuals were observed at North Head.

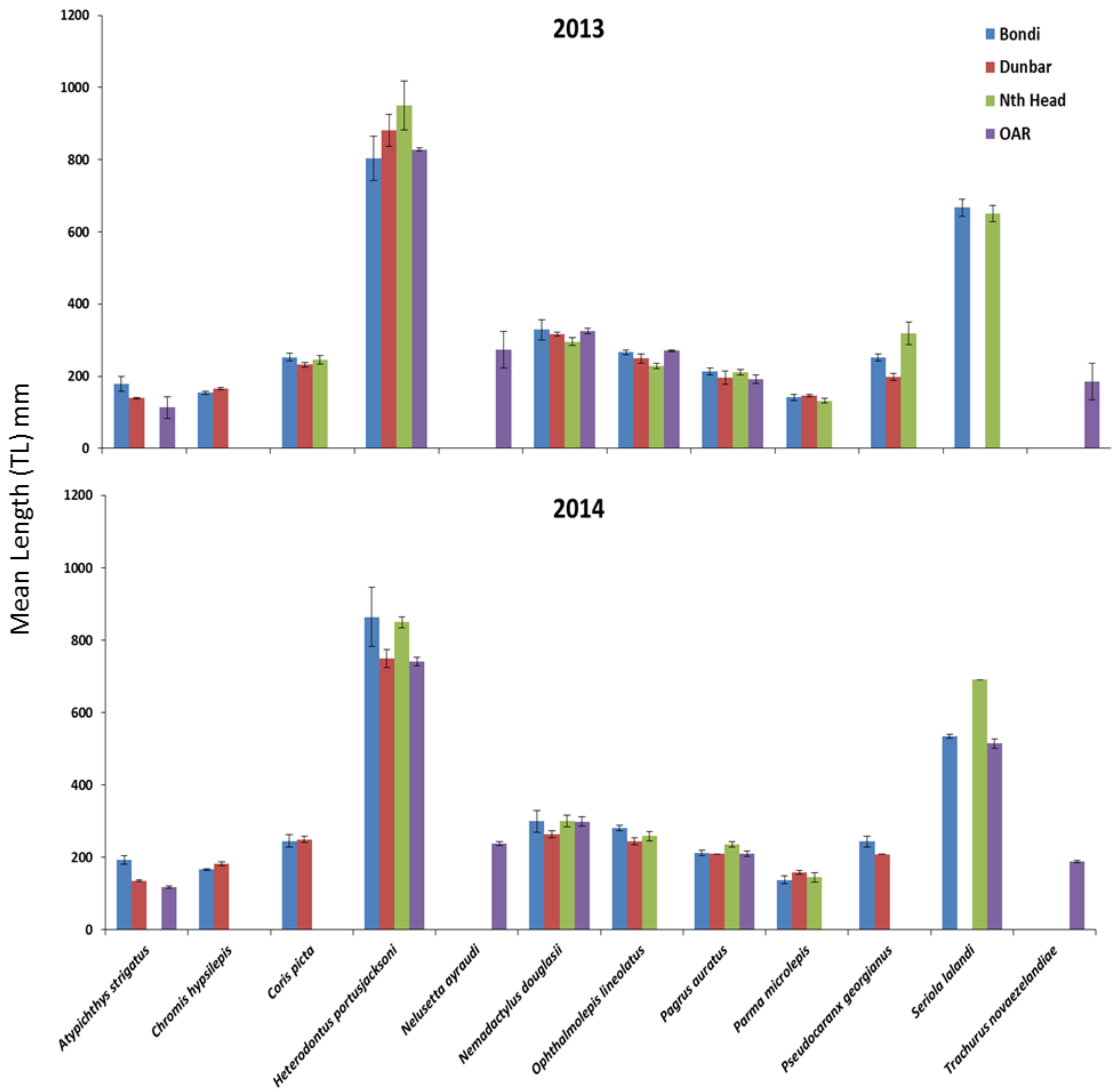

Figure 11 Mean total lengths of the 12 most common fish species at the OAR and control sites during 2013 and 2014 (± S.E.)

A total of nine species were observed in the towed Seaviewer GoPro footage in the pelagic zone around the two OAR towers. Although variable among months, relative abundance (MaxN) of *T. novaezelandiae* and *A. strigatus* was considerably greater than other species in this habitat during 2013 and were also most abundant during 2014 (Figure 12). However, the abundance of other species such as *S. lalandi* and *Pseudocaranx georgianus* also increased during 2014.

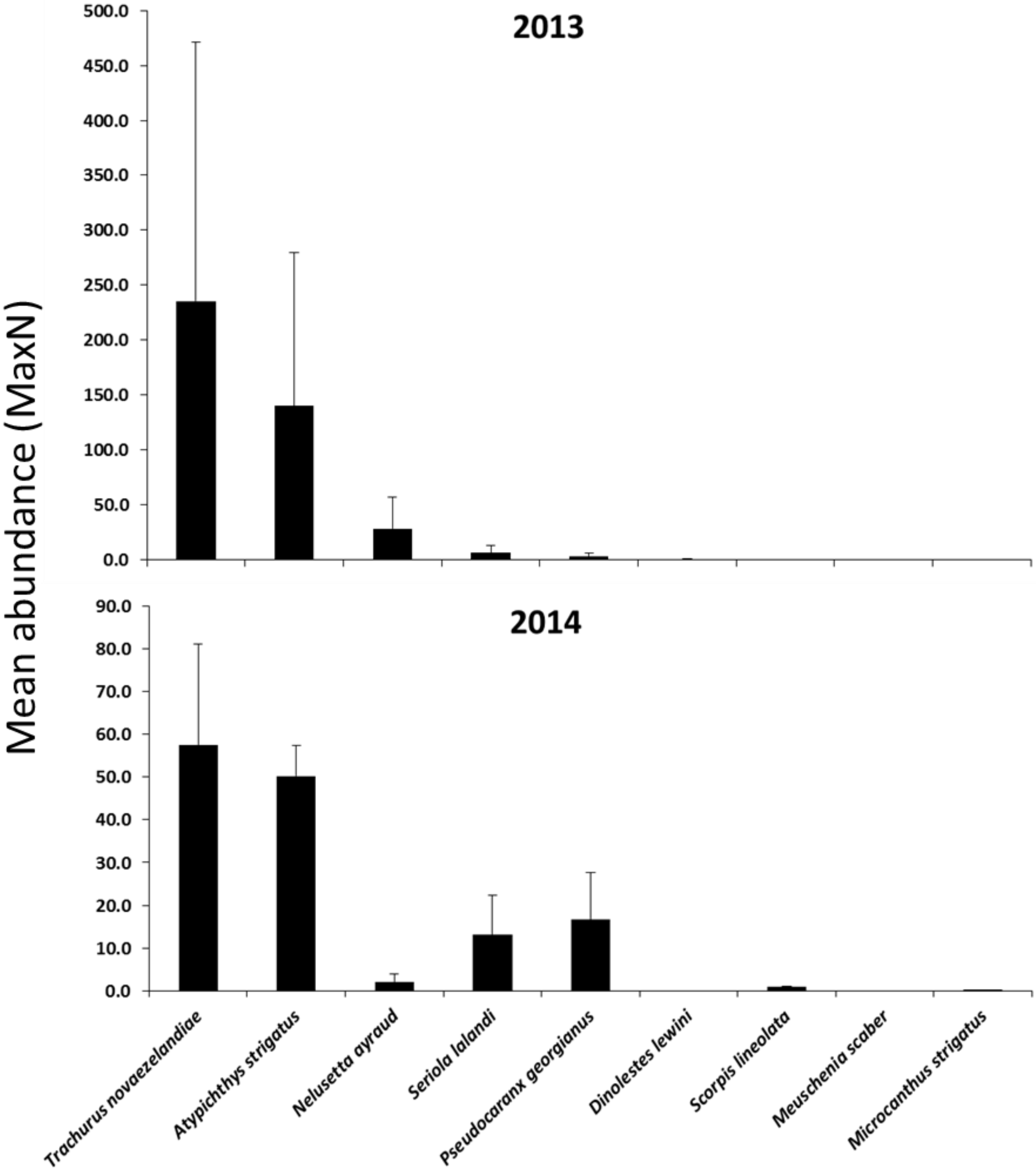

Figure 12 Mean relative abundance (MaxN) of common fish in the pelagic zone around the OAR towers (+ S.E.)

A total of 360 RUD deployments were made around the OAR. Three common species observed in the RUDs include *T. novaezelandiae, A. strigatus* and *Pseudocaranx sp.* (trevally). The abundance (MaxN) of these species relative to distance from the OAR shows that they aggregate around the OAR (Figure 13). None of the common species were detected more than 100 m from the OAR with *A. strigatus* never observed more than 25 m away.

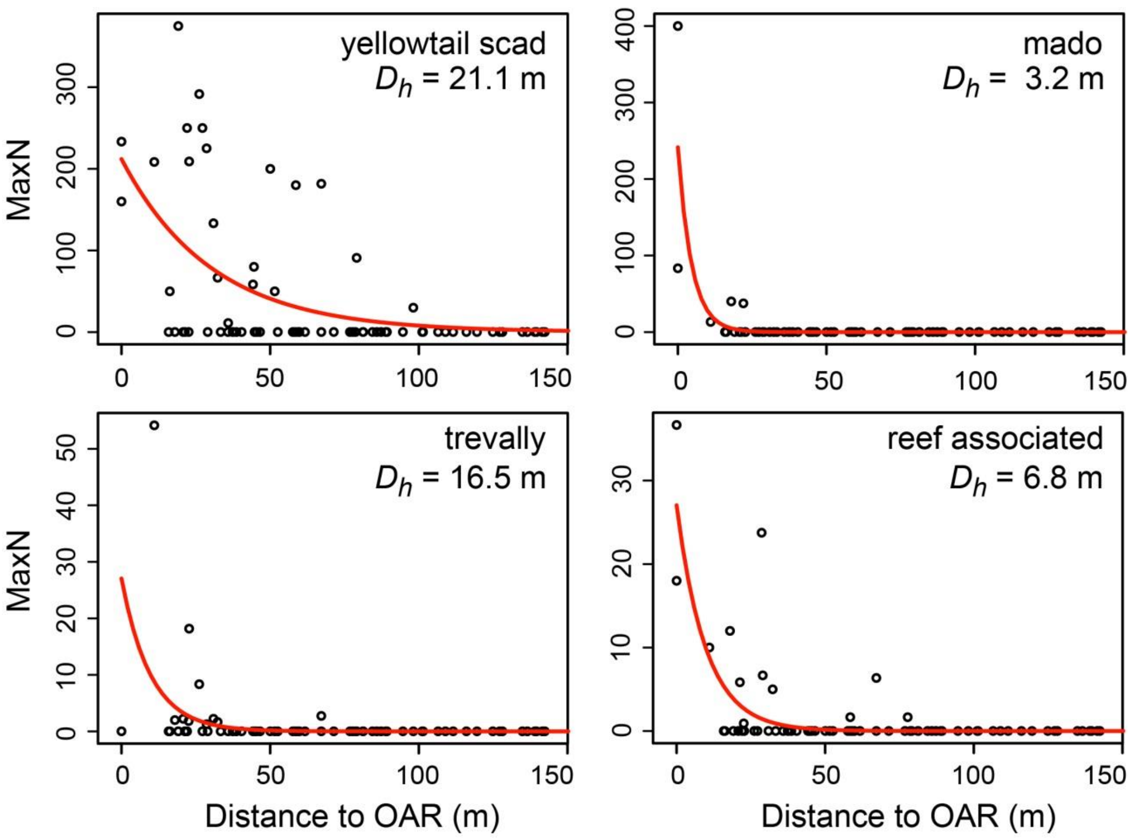

Figure 13 The declining relative abundance (MaxN) of four fish taxa with increasing distance from OAR. Estimated is the distance at which abundance halves (Dh).

5.1.2 Recreational Angling Effort and Annual Harvest

Fishing effort at the OAR was influenced by weather conditions. Greater levels of effort were observed during 2013/14 compared to the previous year, with effort also more evenly distributed across seasons (Figure 14). The trailer-boat ramp survey indicated that most fish harvested from the OAR consist of large reef associated species and pelagics with this pattern consistent during both 2012/13 and 2013/14 (Figure 15).

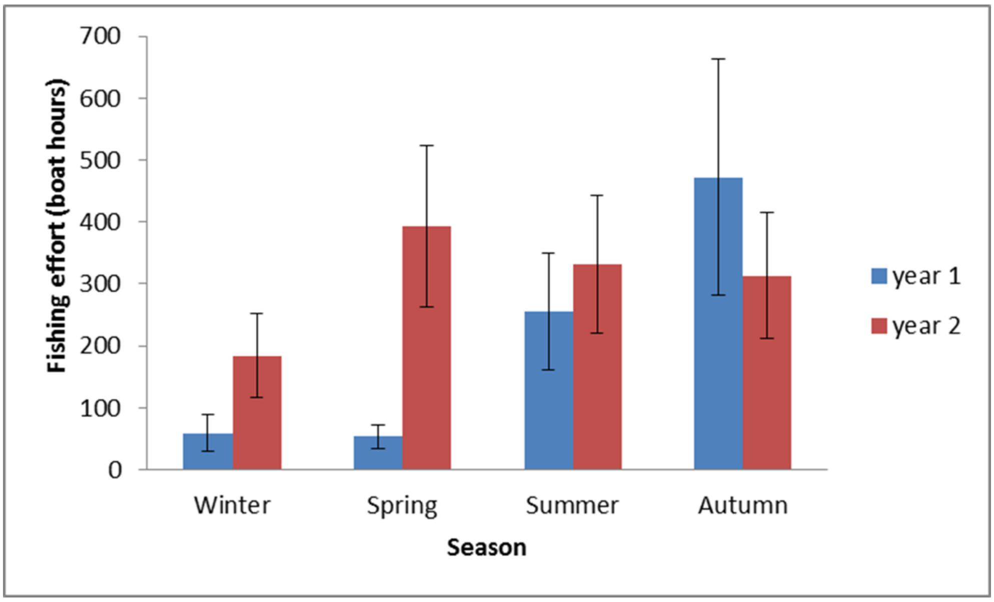

Figure 14 Average (± SE) fishing effort at the OAR site per season for the two sampling years (year 1 is June 2012- May 2013; year 2 is June 2013- May 2014).

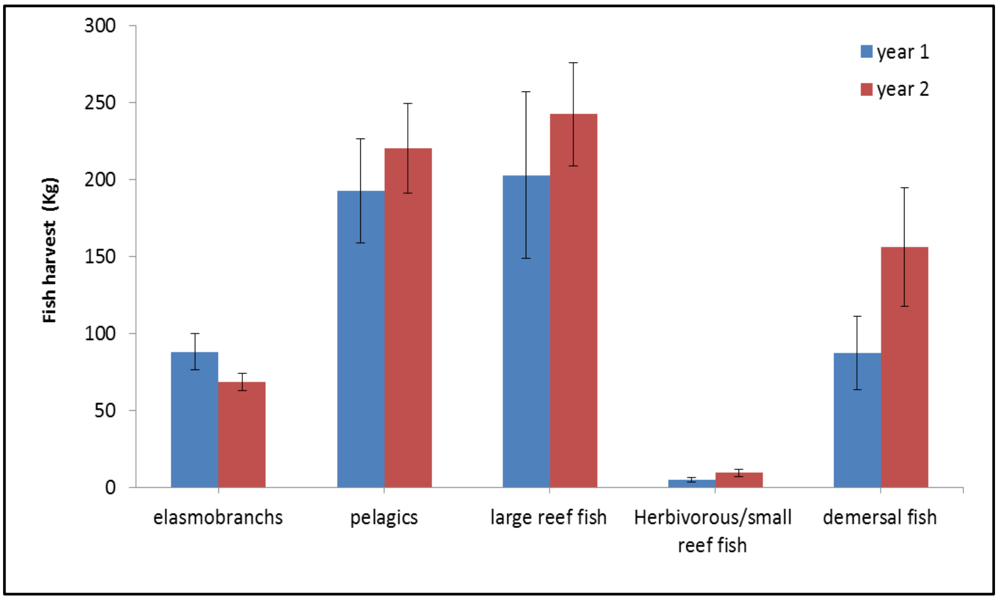

Figure 15 The average (± SE) annual harvest (kg) of common fish groups (34 species) from the OAR site for each of the two sampling years.

5.1.3 Residency Times of Acoustically Tagged Fish

Individuals from 5 of the 7 species tagged remained in the vicinity of the OAR and proximal reefs where VR2 and VR4 receivers were positioned. Movement patterns of these species show signs of connectivity between the OAR and nearby reefs (Table 5). Of the species which were detected at the OAR, Banjo Rays had the highest residency index (Figure 16) while snapper (*Pagrus auratus*) had the lowest, spending only approximately 5% of their time around the OAR.

Table 5 Number of tagged individuals per species detected at the OAR, or natural reef (NR), or both.

Species	Detected at Oar and NR	Detected only at OAR	Detected only at NR	Total
Banjo ray	8	2	0	10
Port Jackson shark	17	0	0	17
Blind shark	1	0	5	6
Snapper	2	0	4	6
Flathead	9	10	2	21

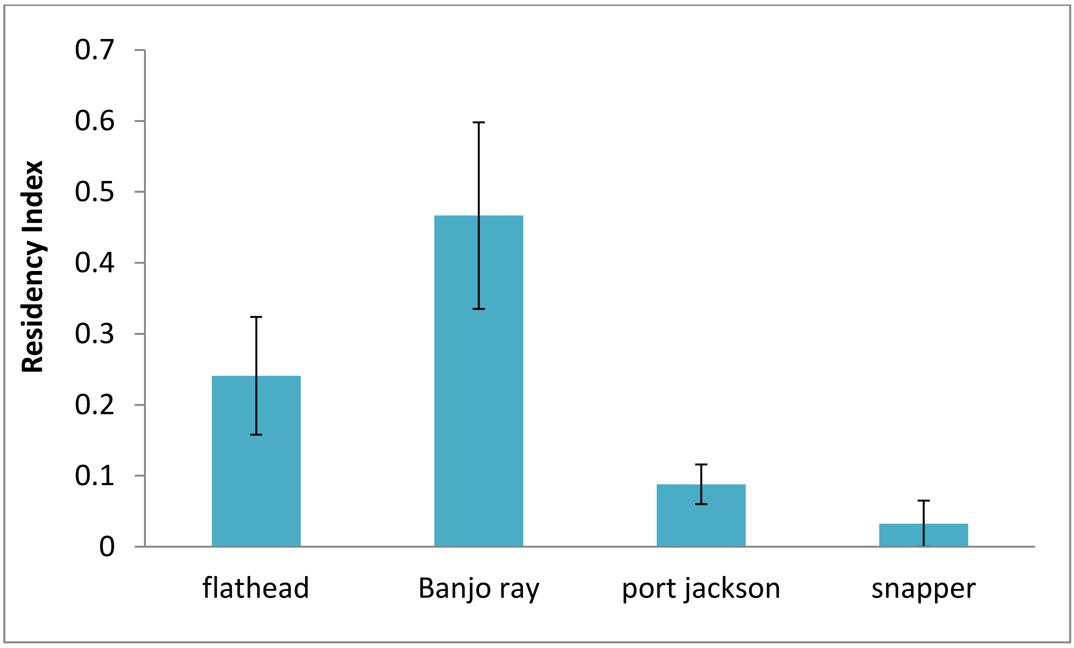

Figure 16 Estimates residency of tagged fish, from July 2013 to January 2015. The residency index is the proportion of total time tagged that was spent near the OAR.

5.2 Priority Two Objectives

5.2.1 Settlement Plates

Comparison of video observation over the three month period following deployment showed that the majority of the structure changed from being completely bare, to totally covered in encrusting organisms including polychaetes, barnacles, algae, bryozoans and hydroids. In total 39 species were identified on the settlement plates with bryozoans showing the greatest diversity (Table 6). No marine pests or species listed under conservation legislation have been identified at the OAR.

Table 6 Invertebrate species identified on settlement plates positioned on the OAR.

Group	Species	Group	Species
Ascidians	*Botrylloides leachii*	Bryozoans	*Conopeum sp.*
	Botrylloides schlosseri		*Disporella sp.*
	Didemnidae sp.		*Microporella lunifera*
	Diplosoma sp.		*Mucropetraliella ellerii*
	Pyura sp.		*Osthimosia glomerata*
	Unknown solitary ascidian		*Parasmittina sp.*
Barnacles	*Austrobalanus imperator*		*Smittina sp.*
	Balanus amphitrite		*Tricellaria sp.*
	Balanus trigonus		*Tubulipora sp.*
	Balanus variegatus	Corals	*Plesiastrea versipora*
	Megabalanus coccopoma	Foraminifera	Unknown foraminifera
Bivalves	*Saccostrea glomerata*	Hydrozoans	*Hydrozoa sp.*
	Theora sp.	Polychaetes	*Pomatocerous sp.*
	Theora sp. 2		*Hydroides elegans*
Bryozoans	*Arachnopusia unicornis*		*Galeolaria sp.*
	Beania discodermidae		*Salmacina australis*
	Beania magellanica		*Sabella sp.*
	Celleporaria nodulosa		*Spirorbis sp.*
	Celleporaris sp.	Sponges	*Sycon sp.*
	Chaperiopsis cristata		

6. Discussion of Key Findings

Fish were quick to colonise the OAR following its deployment and the recruitment of new species continued rapidly through 2012. While new species continued to recruit during 2013 and 2014, the increase in species richness was only modest. Similar patterns in recruitment were observed in artificial reefs deployed in NSW estuaries (Lowry, Glasby et al. 2014) and reflects other studies across a broad range of artificial structures and fish species globally (Bohnsack and Talbot 1980, Manderson and Able 2003). The addition of new species to the OAR resulted in a continued shift in the fish community among years which was not apparent at each of the three control sites. In order to recruit to newly established artificial reefs, fish must transit from existing reef habitat, normally across bare sand. In the first year following the deployment, species such as *T. novaezelandiae and Pseudocaranx dentex* (white trevally), were most common at the OAR, highly mobile species such as these are commonly observed at isolated patches of structured habitat because of their ability to rapidly move across bare sand areas. The increase in species richness over time was a result of recruitment from nearby reefs of fish from various life stages, therefore the proximity of nearby natural reef habitat as well as oceanic currents, which act as a source, are an important aspect in the successful development of fish communities on artificial reefs.

Although the overall species richness at the OAR was slightly lower than some of the natural reef sites, the abundances of species such as *A. strigatus* and *T. novaezelandiae* were significantly higher. High abundances of these species were responsible for the lower diversity index recorded at the OAR. In regards to fisheries enhancement, higher average abundances of a number of important recreational species such as *Pagrus auratus* (snapper), *S. lalandi* (kingfish) *Nemadactylus valenciennesi* (morwong) and in particular *N. ayraud* (ocean leatherjacket) were recorded at the OAR than the control reefs.

The high abundances of *A. strigatus* and *T. novaezelandiae* were also largely responsible in the overall distinction of the OAR assemblage from the three control natural reef sites during all years of monitoring. Fish assemblages at artificial reefs rarely directly mimic those of natural reefs in the region (Rilov and Benayahu 2000, Folpp, Lowry et al. 2013). Although significant advances have been made in the design and construction of artificial reefs, aspects such as the construction material and the size and shape of internal spaces often differ to natural reefs, and are believed to result in the disparity of fish assemblages. Furthermore, natural reefs often form long continuous stretches of structured habitat, while even large artificial reefs generally represent only a smaller isolated patch. Plots of the annual centroids indicate the OAR fish assemblage was more similar to Dunbar than North Head or Bondi. Both North Head and Bondi are large continuous reef systems and the similar size and structure of these sites is reflected in their similar fish assemblages. By comparison, Dunbar, like the OAR, is an isolated reef and this shared factor explains both why Dunbar was distinct from the other control sites and also more similar to OAR. While the four year monitoring program has produced a significant dataset, in reality it spans only the early stages in the development of the artificial reef. Long term studies have revealed that differences between artificial and natural reefs can persist for up to 25 years (Burt, Bartholomew et al. 2009).

Only nine species were recorded in the pelagic zone around the OAR towers, with the community dominated by *T. novaezelandiae* and *A. strigatus.* This differs from the benthic fish community which had not only increased diversity, but also a greater evenness of species. No species were unique to the pelagic region of the OAR, this indicates that a subset of the benthic fish community also moved vertically in the vicinity of the tower sections of the structure. *Atypichthys strigatus* is one of the most abundant fishes on rocky reefs around Sydney and feeds both on plankton as well as benthic organisms (Glasby and Kingsford 1994) which explains their high abundance in both BRUV and pelagic deployments.

The lengths of fish at the OAR were similar to what was observed at each of the three control reef sites during both 2013 and 2014. This indicates that the size cohorts of fish on the OAR are typical of other natural reefs within the region and is not selective to a subset of sizes found on nearby reefs. Only the lengths of fish for which there was sufficient data are presented in this report, many other species were not recorded in large enough numbers at each of the sites to allow for a meaningful interpretation of their lengths.

Fishing effort detected at the OAR demonstrates the local recreational fishing community is making use of the structure. Not surprisingly angling effort is lowest during winter when weather conditions often hinder access to the OAR for trailer-boat fishers. There was an increase in recreational angler effort at the OAR during 2013/14, this may reflect the increased success anglers are having at the reef as fish biomass at the structure continues to increase. Most fish retained by recreational anglers consisted of large reef fish and pelagic species. These types of species are keenly targeted by anglers and it demonstrates that OAR is providing a diverse range of species for recreational fishers to target.

Non-compliance and/or environmental incidents

Visual inspection and video surveys of the OAR identified no structural flaws in any of the OAR components. Inspection of areas around the base of the structure (footings and mooring blocks) did not indicate any significant areas of deposition or scouring. There have been no recorded incidents of non compliance and or environmental incidents involving threatened and /or migratory species. The only threatened species identified at the OAR is the grey nurse shark (*Carcharias taurus*). These sharks were implanted with acoustic transmitters and were detected by the listening station on the OAR. In the 36 months the listening station was operational at the OAR, only 5 grey nurse sharks were detected over a total period of 25 minutes. This strongly indicates that these sharks were not resident at the OAR but rather passed by the receivers positioned on the OAR.

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