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BIOLOGICAL MONITORING OF THE EX-HMAS BRISBANE ARTIFICIAL REEF: PHASE II - HABITAT VALUES

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EXECUTIVE SUMMARY

1. The ex-Australian Navy ship HMAS *Brisbane* was scuttled off the Sunshine Coast on 31 July 2005 to create an artificial reef and to provide world-class diving opportunities on a large warship in South-East Queensland. The wreck has since underpinned the expansion of the local diving and associated tourism industry, and it has become a valuable natural and economic feature of the region. The wreck also forms a significant addition to hard-substrate habitats of the local nearshore marine zone.

2. This report summarises the second inventory of the diversity of larger, sessile invertebrates and fish that inhabit the wreck after the scuttling. In 2008 the University of the Sunshine Coast and the Queensland Museum were commissioned by the EPA / QPWS to survey the benthos and fish assemblages associated with the wreck three years after the sinking to document the types and rates of faunal changes.

3. This report contrasts the biodiversity and composition of the biotic assemblages between the wreck and adjacent natural reefs that most closely resembled the structural complexity of the wreck, to determine whether the artificial assemblages had converged with natural assemblages over the three year period.

4. Species richness of invertebrates and algae on the wreck had clearly increased and species composition had considerably changed due to colonisation by new animal groups (eg. corals) which were not present in the 2006 survey.

5. Community structure of invertebrates and algae varied over several spatial scales on the wreck. 87 species were recorded from the external superstructure; 25 species from the decks; 49 species in internal areas; 49 species from upper hull areas; and 36 species from the lower hull near the seafloor. Horizontal surfaces supported fewer species with substantially reduced cover. The colonisation of the decks with various species of hard and soft corals underlines the predominance of spatial heterogeneity in community structure.

6. For some invertebrate groups the fauna colonizing the wreck is broadly representative of that on adjacent natural reefs of the Inner Gneering Shoals. Conversely, the dominant species of sponges, corals, and sea squirts on the wreck are not proportionally representative of the surrounding natural reef.

7. Overall, the diversity of benthic invertebrate assemblages was higher on the natural reef sites than found on the wreck. The wreck supported 79 species of sessile invertebrates and algae after one year and 120 species after three years, lower than the 173 species on the natural reef. Trajectories in species richness varied greatly between taxonomic groups, most notably for corals which took more than one year to colonize the ship.

8. The wreck continues to support a high fish biomass relative to that found during previous surveys on the site, and to that on nearby natural reefs. Trends in abundance levels

have generally been steady, or have had moderate deviations up or down. Some piscivores increased, omnivores recorded both increases and declines, while planktivores and herbivores mostly registered modest declines.

9. The wreck continues to attract additional species of fishes, with 192 species now recorded cumulatively between 2006 and 2008. However net resident species totals have remained relatively constant, with surveys in July 2006 recording 133 species, followed by 111 in November 2006, and 139 during the most recent in November 2008.

10. Composition of the fauna continues to evolve, most likely according to competitive pressures between fishes and changes in available food and habitat led by the development of invertebrate communities over time.

11. Since 2006 new colonizers were outnumbered by emigrants, indicating fish communities may be approaching a more mature phase. In the most recent survey, 40 of the 139 species had not been recorded in 2006, but 52 of those found during 2006 were not recorded in 2008.

12. Species new to the wreck included several serranids (rock cods and basslets), pempherids (bullseyes), labrids (wrasses) and gobiids (gobies), while those now absent include priacanthids (bigeyes), some carangids (trevallies and scads), several pomacentrids (damselfishes), an acanthurid (surgeonfish) and most monacanthids (leatherjackets).

13. The deck area remains the most favoured habitat for fishes on the wreck, with 69 percent (or 133 species) of all species found in this area. The sector that had the least diversity overall was the internal areas, with only 40 percent of the fauna, or 76 species.

14. Evidence of recruitment and maturation on the wreck has been observed for two common serranid fishes, Purple Rock Cod, *Epinephelus cyanopodus* and Maori Rock Cod, *E. undulostriatus*. Recruitment of small juveniles was observed in the early stages of the wreck, followed by apparent site fidelity and retention of adults up to the present. This indicates the wreck has acted as a self-generating system and is not merely encouraging migration of adults to the wreck at the expense of nearby natural reef areas. The population of Snapper, *Pagrus auratus* on the site has also experienced progression in size classes. Large adults were previously lacking around the site, but are now present in significant numbers, along with the juveniles and subadult stages previously noted.

15. Surveys on natural reefs adjacent to the wreck in summer/early autumn 2009 recorded 193 species of 40 families, versus 192 species of 47 families found cumulatively on the wreck from 2006 to 2008. However, resident species recorded on the reef outstrip those found at any one time on the wreck by a large margin (39-74 percent). Of the larger families, chaetodontids (butterflyfishes), pomacentrids (damselfishes) and labrids (wrasses) were much more diverse on the reefs, carangids (trevallies and scads) and lutjanids (tropical snappers and fusiliers) were much more diverse on the wreck, while serranids (rock cods

and basslets) had similar numbers of species in both areas.

16. Biomass on the wreck was significantly greater than that in similar-sized areas on the natural reef, being composed of greater numbers of generally larger fish. Overall, large piscivores, molluscivores, omnivores and planktivores were more abundant on the wreck, while groups with species more specialised on benthic invertebrates (especially corals) were clearly more common on the reef environments.

17. Physical habitat features (e.g. depth, aspect) are important in determining the rate of colonisation by encrusting assemblages ('fouling communities'). In 2006, we found that there was very little difference in the coverage of sessile fauna between the starboard (exposed) and port (sheltered) sides of the wreck. In 2008, the composition of epifaunal assemblages differed between the starboard and port sides of the wreck at both 12 and 18 m depth. The difference between depths was due largely to the reduced coverage of the bryozoan, *Celleporaria* sp. 1, and increased coverage of the sponge, *Batzella* sp. 4217.

18. In 2006 and 2008, we compared vertical surfaces on the port and starboard sides of the wreck with horizontal surfaces on the main and upper decks. The vertical sides were settled by more species at significantly higher densities than the horizontal surfaces. This might be explained by smothering by sediment which settles at greater rates on horizontal surfaces. However, the relative dominance of particular species in 2006 had changed over time, with barnacles, bivalves and bryozoans dominating assemblages in 2006, and bryozoans and sponges dominating in 2008.

19. Sessile assemblages on the artificial reef were compared with two adjacent natural reefs, to determine whether the composition of epifaunal assemblages on the artificial reef became more representative of subtidal reefs in the area. The benthic assemblages on the wreck are currently in a state of flux, with colonisation still progressing. Shifts in epifaunal assemblage structure between the artificial and natural reef were more pronounced for fauna of vertical surfaces. Communities on horizontal surfaces diverged much less between the artificial reef and the natural reefs.

20. There are indications of continual community change on the wreck, with a trend towards greater similarity between natural and artificial reef communities over time. Nevertheless, three years after the scuttling, the structure of epifaunal assemblages on the artificial reef remains quite different from that found on adjacent natural reefs. Arguably, the assemblages on the wreck are still in succession, but the rate at which faunal diversity will increase and the assemblages may change is not known. Therefore, a key recommendation of this study is to implement a continuing medium-term scientific monitoring programs that records the nature and dynamics of biological colonisation.

21. The wreck is visited by a large number of divers, but awareness of its ecological value appears to be limited outside the diving community.

It is recommended to extend and improve communication, education, and outreach programs to increase the awareness of the ecological value of the ex-HMAS *Brisbane* artificial reef in a broader audience.

1. INTRODUCTION

The HMAS *Brisbane* was a 133 metre, Charles F Adams Class DDG, Guided Missile Destroyer, with a long history of distinguished service in the Australian Navy. After decommissioning, the Queensland Government obtained her from the Commonwealth to create an artificial reef off the Sunshine Coast, and the ship was scuttled there in August 2005.

In 2006 the EPA commisioned the University of the Sunshine Coast and the Queensland Museum to undertake a biological baseline surveys of the ex-HMAS *Brisbane*. In 2008, three years after the scuttling, the EPA commisioned a follow-up survey of the benthos and fish assemblages associated with the wreck to document changes to the biota. To test whether the conventional motivation for scuttling ships - creating “valuable artificial reefs” - holds true in the current situation, a survey was undertaken of the biodiversity and composition of assemblages between the wreck and adjacent natural reefs (Inner Gneering Shoals) that most closely resembled the structural complexity of the wreck.

Artificial reefs are spatially complex habitats that provide opportunities to quantify colonisation of newly created, artificial substrates by marine organisms (Cummings, 1994; Svane & Petersen, 2001, Walker *et al.*, 2007).

Ships, aircraft, and other large structures are deliberately sunk. Coastal communities are increasingly actively promoting artificial reefs as a means of providing new destinations for recreational SCUBA diving tourists. The ex-HMAS *Brisbane* was scuttled to create an artificial reef that would become a premier dive destination in the region. Artificial reefs are not only an important asset in terms of recreational value (e.g. diving, fishing, surfing, etc.), but also ecological values (e.g. new habitats, refugia for benthic invertebrates and fish (Walker *et al.*, 2007 Bortone & Kimmel, 1991; Malcolm et al., 1999; Svane & Petersen, 2001). Furthermore, because many coral reefs are declining testing the potentially positive effects of artificial reefs for conservation purposes is important (Wilhelmsson D., 1998; Nadon & Stirling, 2005).

Epibiota, the attached plants and animals that settle and grow on hard substrata, are a major component of biogenic structure in subtidal habitats, particularly on artificial reef structures. Epibiota provide food resources for consumers, secondary habitat for other benthic invertebrates, and increased habitat complexity, and therefore have large effects on the distribution and abundance of fish (Mintz *et al*., 1994; Santos *et al,* 2005). The composition and amount of sessile marine flora and fauna, which itself may vary considerably between different parts within the artificial habitat and considerably between natural and artificial structures, may influence the number and types of fish associated with these artificial habitats (Mintz *et al*., 1994; Santos *et al,* 2005).

On wrecks, the abundance and diversity of fish has been reported to be positively correlated with the amount of foliose algae, mussels, sponges and solitary ascidians (Clynic, 2004; Santos *et al*., 2005). These epifaunal assemblages may undergo marked changes in biomass and species composition during the initial stages of colonisation of the wreck (i.e. succession) (Walker *et al.*, 2007). Variability reduces with increasing length of exposure until a artificial reef community is established (Brown, 2005). Most artificial reef studies have examined only the early colonisation stages. Thus, the time required for the development of stable and diverse assemblages is generally unknown or poorly understood, but may be a decade or longer (Perkol-Finkel & Benayahu, 2005). Equally, comparative studies between artificial (AR) and natural reefs (NR) are uncommon, but wrecks may be distinct compared with neighbouring natural reefs (Perkol-Finkel & Benayahu, 2005).

Several artificial reefs have been created adjacent to major Australian population centres (e.g. ex- HMAS *Swan* off Perth - Anon., 2004, the ex-MV *Marchart* off Darwin - Hooper & Ramm, 1989), but the rates and trajectories of biological colonisation of the shipwrecks have not been determined. Therefore, this monitoring program was essential to assess whether artificial reefs simply become fish attracting devices (FADs), and thus contribute little to enhancing biodiversity productivity, or become established as benthic ecosystems that can enhance the habitat and biological diversity of an area through enhanced recruitment and community complexity (Carney, 2005; Walker *et al.*, 2007).

The sinking of the ex-HMAS *Brisbane* in July 2005 provided a unique opportunity to undertake such a biological monitoring program. This report contrasts the findings from the comprehensive field survey undertaken on the wreck in July and November 2006 (Schlacher-Hoenlinger *et al.;* 2006, Walker *et al.*, 2007), to the intensive follow-up sampling event between November 2008 and February 2009. Our monitoring program compared the invertebrate and fish diversity on the wreck over time, and also determined which factors (e.g. exposure, aspect, depth) influence the species composition of fouling communities on the wreck. Furthermore, a broad comparison of the wreck-associated fauna was made with that of adjacent natural reefs in the area.

2. MATERIALS & METHODS

The field surveys comprised three monitoring modules.

- 1. biodiversity surveys of macrobenthic invertebrates that have colonized the wreck over the three year period since the scuttling of the ship and of the adjacent natural reefs,
- 2. biodiversity surveys of the fish fauna on the wreck and adjacent natural reefs, and
- 3. a survey of the encrusting micro-invertebrates and algae (‘fouling communities’) on the vertical and horizontal surfaces of the wreck and adjacent natural reefs.

All field work was done on the ex-HMAS *Brisbane* (Long 26º 36’ 58.0’’ S; Lat 153º 10’ 11.5’ ’E), as well as on two natural reef sites on the Inner Gneering Shoals, adjacent to the wreck: ‘Hanging Rock’ (Long 26º 38’ 53.6’’ S; Lat 153º 11’ 06.9’’ E), and ‘The Trench’ (Long 26º 39’ 05.3’’ S; Lat 153º 09’ 44.2’’ E; Fig. 1)

These natural reef sites were selected due to their proximity to the wreck (both are only 4.0 km from the wreck), and due to having a structural complexity (vertical walls, caves and overhangs) that closely resembles the wreck.

The underwater field surveys comprised 68 dives in dive pairs with approximately 50 hours logged dive time (Number of dives 1. Ex-HMAS *Brisbane*: Macroinvertebrates: 16; Fish 12; Fouling communities 4; Inner Gneerings: Macroinvertebrates: 16; Fish 16; Fouling communities 4; Table 2 & Table 4).

2.1. Biodiversity assessments

2.1.1. Rapid ecological assessment (REA) of sessile invertebrates, small mobile fauna, and algae

The assessment of sessile biota and small mobile fauna on the ex-HMAS *Brisbane* was primarily designed to document the biodiversity and community composition of macro-invertebrates on the wreck. The wreck and the adjacent reefs were surveyed using the one-off rapid ecological assessment technique (REA) modified from Richards *et al* (2007) and Fabricius & McCorry (2006) (Table 1 & 2). Relative abundances on the wreck and the reef sites of macro-invertebrates were visually estimated and a relative abundance ranking, using six ordinal categories, was given to each taxa: 0 = absent; 1 = rare (one or two); 2 = occasional (three to five); 3 = frequent (six to ten); 4 = common (eleven to twenty-five); 5 = dominant (over twenty-five).

The baseline surveys of macro-invertebrates, algae, and encrusting fauna and flora involved swimming transects along the length and breadth of the wreck using SCUBA, examining representative horizontal and vertical surfaces, and also surveying the seabed surrounding the wreck out to a specified distance (3 m). Swimming transects of approximately 45 minutes were conducted throughout pre-determined parts of the wreck (hulls at two depth levels; superstructures, and various decks) and all species were recorded and their ranked abundances noted. In addition, two adjacent reef sites (‘Hanging Rock’, ‘The Trench’) were surveyed using REA at a depth range of 15 to 18 metres.

A comprehensive follow-up survey of the ex-HMAS *Brisbane* was undertaken in November 2008 followed by a comparative survey of two adjacent reef sites (at a similar depth and orientation) closest to the wreck in January / February 2009. The data were used to provide a preliminary assessment of the differences in community composition between the wreck and surrounding rocky reefs.

The techniques used for REA included underwater photography as well as extractive sampling of representative taxa (Algae, Worms, Porifera, Cnidaria, Mollusca, Crustacea, Bryozoa, Echinodermata and Ascidiacea). The underwater field surveys for macro-invertebrates involved eight dives at the wreck and eight dives at the reef sites. All biota were photographed *in situ* and a collection of voucher specimens was made and deposited at the Queensland Museum. This collection of sessile and small mobile fauna on the wreck and adjacent reefs was used for taxonomic quality assurance and will serve as a reference collection for future monitoring.

Species lists of algae and macro-invertebrates from the two field surveys were completed (Table 1 & 2). Estimates of species richness are highly dependent on sampling effort. Therefore, the species lists presented in this report reflects accurately all species collected, observed, and identified during the field surveys between November 2008 and February 2009, but it should not be taken as a “complete” inventory of species inhabiting the wreck and adjacent reefs. It does – with high probability - contain the majority of macro-invertebrate species occurring on the wreck at the time of the surveys, but more species are likely to be encountered with greater sampling and collection efforts.

2.1.2. Rapid visual census of fishes (RVC)

Fish communities on the wreck and two nearby natural reef sites were surveyed using rapid visual census techniques (RVC) modified from Hutchins (2001). Sheets of waterproof paper printed with pre-prepared lists of the most common fish species known from the Sunshine Coast area were mounted on a clipboard and used to record fish species and score their abundance on a $\log_5$ scale. Swimming transects of approximately 45 minutes were conducted throughout pre-determined parts of the wreck and reefs, with all observed fish species recorded and scored. Numbers were continuously updated during each dive as additional fishes were observed. Although this technique is most effective for the more conspicuous species that can be located, observed and identified accurately underwater, small and cryptic species were also sought and recorded to the greatest extent allowable by available dive time.

During each visual survey, a second diver recorded high definition underwater video and/or still photography, aimed at capturing detailed footage of as many fishes as possible along the same track as the diver taking visual recordings. This footage was later employed to assist in validating identifications of small species, or those for which accurate discrimination underwater by eye was problematic. In some instances species were recorded only by photographic techniques. In these cases, abundance was determined by the number of individuals recorded on images.

The wreck was broadly divided into a number of sectors, and separate counts were made for each of these areas to determine if there were corresponding differences in fish diversity and abundance (Table 3). The sectors were delineated as follows: a) Superstructure (mostly vertical surfaces, depth ~3-10 m), b) Decks (mostly horizontal surfaces, depth ~10-18 m), c) Internal (shaded areas with vertical and horizontal surfaces, depth ~12-22 m, d) Lower Hull (vertical surfaces of the wreck and adjacent sandy substrate, depth ~18-27 m). For the two areas with external vertical aspects (superstructure and lower hull) fishes within a horizontal radius of up to 5 m were included in the counts. Each dive concentrated solely on a particular sector. Fish noticed to have moved between sectors of the wreck during recording events were counted in the sector that they appeared most closely associated with. Counts were converted from actual and estimated numbers to a $\log_5$ scale of abundance (Hutchins, 2001). Initial surveys were undertaken in July 2006, and repeated using the same methods in November 2006 and November 2008 to allow assessments of temporal variability.

The natural reef sites chosen for comparative surveys formed part of adjacent reef systems more extensive in area than the the wreck. They contained fewer large, heavily sheltered areas, included features less vertically prominent, and unlike the wreck were not isolated within a much broader area of mostly bare sandy substrate. For these reasons, it was anticipated that the available habitat on the natural reefs would be less effective in aggregating and holding fishes to specific zones, so no attempt was made to differentiate between various sectors or habitats on the natural reefs, as was done for the wreck. Hence the data will not provide indicators of the relative value of individual structural elements of the natural reefs. Recordings from ‘Hanging Rock’ and ‘the ‘Trench were taken across all major habitat types and serve to compare overall fish species diversity and abundance between the wreck and natural reefs. Surveys of these sites were carried out from late January to early March 2009.

2.2. Encrusting biota (‘fouling communities’)

2.2.1. Field surveys (PHOTP – photo quadrats analysed by point sampling)

The quantitative assessment of encrusting macro-invertebrates on the ex-HMAS *Brisbane* was designed to quantify the cover and community composition of encrusting biota on the wreck. Three key-objectives were addressed: 1) determine spatial differences between vertical surfaces on the sheltered port and exposed starboard sides of the wreck at two different depths (12 and 18 m) 2) examine the spatial variation across different surface orientations (vertical vs. horizontal) on the wreck, at two depths (12 and 18 m), and 3) compare patterns of community composition of encrusting faunal assemblages between the wreck and two adjacent reefs at a similar depth (18 m) and with similar orientation (vertical and horizontal; Fig. 1).

The composition of the encrusting assemblages were quantified using a spatially replicated survey design that included; a) two depth levels (12 m & 18 m) on both the starboard and port side of the wreck, and b) horizontal and vertical surfaces matched for depth at 12 m and 18 m, (Fig. 1). The encrusting assemblages found on nearby subtidal rocky reefs were also quantified on horizontal and vertical surfaces at two sites ('Hanging rock' & 'the Trench'). See Fig. 1 for the location of reef sites compared with the wreck. Two 10 m long transects were sampled near the bow and stern, at 12 m and 18 m depth on both the starboard and port sides of the wreck. Two transects were also sampled along the main deck (horizontal surface) at approximately 12 m and 18 m depth.

At each site the encrusting assemblages were documented using a photo-transect method. Digital photos were taken with an Olympus 4MP UZ digital camera, at each of 20 replicate plots separated by 1 m, along the transect line. Each photo quadrat covered an area of 625 cm^2. Representative voucher samples were photographed and collected for identification to the lowest possible taxonomic level.

In the laboratory, each photo-quadrat was analysed using the image analysis software 'Coral Point Count' (Kohler & Gill, 2006). The area inside the photo-quadrat was selected, then 80 randomly distributed points were superimposed over each image, and under each point the identity of each taxon was recorded (PHOTP). We determined the number of points required to assess the composition of sessile assemblages by selecting 20 quadrats from both a vertical and horizontal site, then analysing them with 20, 40, 60, 80 and 100 points. We determined the total number of species using species accumulation curves and found that 80 points maximized the total number of species in both horizontal and vertical quadrats. Using 80 points also provided the most precise measure of total sessile cover.

2.2.2. Data analysis

The spatial variation of assemblages between different exposures (exposed-starboard versus sheltered-port), depths, and orientations was analysed using non-metric multidimensional scaling (nMDS) based on a Bray-Curtis similarity matrix, with no transformation of the data and comparisons among groups were done with analysis of similarity (ANOSIM; Clarke, 1993). The species contributing to separation among different groups were identified using the SIMPER procedure (Clarke, 1993).

Species accumulation curves were plotted in PRIMER using the species area routine with 999 random permutations. The curves were used to determine the total number of species collected across successive quadrats grouped within the replicate transects for each of the following; 1) depth and aspect, (2) orientation and depth and (3) location inside and outside the wreck.

Spatial variation in total cover, species density (number of species per 625 cm^2) and the cover of main taxonomic groups was analysed using the following univariate statistical methods: (1) the difference between exposure and depth was examined using a two-factor crossed ANOVA with exposure (port or starboard) and depth (12 m, 18 m) as factors, (2) the difference between orientations at two depths was examined with a crossed

ANOVA with orientation (vertical and horizontal) and depth (12 m & 18 m) as factors, and (3) the difference between the wreck and adjacent reefs at 12 and 18m was examined, using a one-way ANOVA with location as the single factor. Homogeneity of variance was checked with Cochran's test; when variances were heterogeneous ($p<0.05$), the percent cover data were arcsine transformed and species density data were log transformed (Underwood, 1981).

Our null hypothesis is that over time, the sessile benthic assemblages on the wreck would become more similar to those on nearby rocky reefs. To test this hypothesis we compared the assemblages sampled at18 metres in 2006 and 2008 with those on the rocky reefs, using ANOSIM. Given the large differences in community composition between surface orientations (vertical and horizontal) we assessed changes separately for each orientation. Data were converted to a Bray-Curtis similarity matrix and analysed used a nested two-factor ANOSIM, with sites nested in location (wreck or reef).

3. RESULTS

3.1. Invertebrates

3.1.1. Temporal and spatial changes in invertebrate diversity and species composition

Colonisation of the wreck has progressed considerably since the scuttling of the ship in 2005, and the survey in 2006 (Schlacher-Hoenlinger *et al.*, 2006; Walker *et al.*, 2007). The wreck has become an important habitat for invertebrates (Fig. 4-14; 23).

Although the entire surface area of the wreck had been covered with marine life one year after the sinking, the assemblages of epifauna changed considerably with a longer colonisation period. As predicted in the previous survey, community composition, abundances, biomass, structural complexity and diversity changed within a relatively short period of time. In 2006, assemblages were dominated by oysters and barnacles. These pioneer species provided microhabitats for other invertebrates, especially crustaceans, such as juvenile rock lobsters, banded coral shrimps, and crabs. In 2008 / 2009 larger barnacles had declined, and with it its associated in-fauna, due to colonisation of more competitive species such as sponges and the recruitment of new groups, such as corals (Fig. 5-14; 23).

Comparative surveys yielded 79 species of macro-invertebrates and Algae in November 2006 and 120 species in 2009 (small, mobile crustaceans and shelled molluscs excluded). Overall species richness clearly increased, and species composition changed considerably. While in some groups species richness remained stable, in others it decreased. Some new taxa were recruited, not recorded in the 2006 survey. Comparison of the two surveys revealed the following changes in species composition and number of species (Table 1; Fig. 23B; Appendix 1):

- Tubeworms: 2006: 2; 2009: 5;
- encrusting Porifera: 2006: 14 ; 2009: 11;
- massive Porifera: 2006: 11 ; 2009: 14;
- Cnidaria: 2006: 4 ; 2009: 19;

- shelled molluscs (without small, mobile fauna): 2006: 12 ; 2009: 11;
- nudibranchs: 2006: 1 ; 2009: 11;
- Crustacea (without small, mobile fauna): 2006: 7 ; 2009: 6,
- Bryozoa: 2006: 9 ; 2009: 8,
- Echinodermata: 2006: 4 ; 2009: 9;
- Ascidiacea: 2006: 12 ; 2009: 20.

The biggest changes were within the group Cnidaria. Five species of hard corals, 9 species of soft corals, and 4 species of large anemones were new colonizators of the wreck.

The number of molluscan species more then doubled, due to the additional appearance of nudibranchs on the wreck. Epibiota, especially lace corals (bryozoans) and algae, provide important resources, such as food and shelter and therefore have considerable effects on the distribution and abundance of nudibranchs. Sponges showed similar abundances in 2009 as in 2006, but here was a distinct shift towards larger specimens and more 3-dimensional growth. The abundance of crustaceans decreased resulting from the loss of habitat from reduced populations of larger barnacles. In particular, the numbers of Lobsters had decreased between these two surveys.

Community structure varied between wreck infrastructure. The number of species found on different parts of the wreck were as follows (Table 2; Fig. 23A):

- superstructure: 87 species;
- decks: 25 species;
- internal: 49 species;
- upper hull: 49 species;
- lower hull near the seafloor: 36 species.

Assemblages were substantially less diverse and abundant on the lower part of the hull and on the sediment-laden decks, but were most diverse on the superstructure and inside the wreck.

The low diversity on the lower parts of vertical sides is probably related to residual antifouling paint, which can retard the settlement of fouling species (Walker *et al.*, 2007; Svane *et al.*, 2006; Schlacher-Hoenlinger *et al.*, 2006). Nevertheless, colonisation at this depth had clearly progressed since 2006 and the abundance and richness of the biota had clearly increased. As the presence of antifouling paint confounded a pure depth effect on settlement in the 2006 survey, the lower part of the hull was only investigated using the rapid Ecological Assessment technique (REA), but not included in quantitative investigations.

One of the most significant findings was the appearance of corals (Fig. 8-9). Even though horizontal surfaces supported fewer species at substantially reduced cover, the colonisation of the decks with several species of hard and soft corals underlines the importance of structural heterogeneity created by the artificial reef infrastructure.

In 2006, the majority of taxonomic groups sampled had, with the exception of tubeworms, significantly higher cover on the outside of the wreck in comparison to the internal spaces. Inside the ship, species richness and diversity was reduced, with small barnacles, ascidians, fan worms and several species of sea fir dominant. In the 2008 / 2009 survey marked increase in species richness was observed inside the wreck, which made this sector of the wreck the second most diverse overall (Fig. 23A). High biodiversity inside the ship and on the superstructure may be related to favorable settlement cues for pelagic larvae.

Overall, the colonisation of the wreck with sessile invertebrates appears to have moved towards a more natural stage of colonisation. More biological monitoring is required to determine future trajectories (Appendix 1).

3.1.2. Comparison of invertebrate species composition between the wreck and adjacent natural reef habitats

An extensive collection of invertebrate groups exist in the Queensland Museum for seafloor habitats off the Sunshine Coast, particularly from the Inner and Outer Gneering Shoals. Between 1991 and 2000 the reefs off the Sunshine Coast were sampled by the study team from the Queensland Museum, and a rich fauna of sessile marine invertebrates, representing a unique fauna in this biogeographic transition zone, was recorded (Hooper & Kennedy, 2002). Therefore, in this present survey, we could identify most samples using underwater photographic techniques to minimize the impact from collecting. New voucher specimens were collected from natural reefs in this present survey only where there was ambiguity in identification from photographic documentation (e.g. cryptic species).

Comparative surveys in 2008 / 2009 of the ex-HMAS Brisbane and the Inner Gneering Shoals yielded 120 species of macro-invertebrates and algae on the wreck and 173 species on the natural reefs (small, mobile crustaceans and small, shelled molluscs excluded) for the same sampling effort. Even if species richness was much greater on the natural reefs, species composition, was broadly comparable (Table 2). Comparison between the wreck and the reef sites revealed the following differences in species richness (Fig. 23B):

- Tubeworms: wreck: 5; reef: 3;
- encrusting Porifera: wreck: 11 ; reef: 8;
- massive Porifera: wreck: 14 ; reef: 32;
- Cnidaria: wreck: 23 ; reef: 57;
- shelled molluscs (without small, mobile fauna): wreck: 11 ; reef: 9;
- nudibranchs: wreck: 11; reef: 17;
- crustaceans (without small, mobile fauna): wreck: 6 ; reef: 2;
- Bryozoa: wreck: 8 ; reef: 7;
- Echinodermata: wreck: 9 ; reef: 15;
- Ascidiacea: 2006: 20 ; 2009: 14.

For some invertebrate groups the fauna colonizing the wreck is broadly representative of natural reefs in the Mooloolaba area. Conversely, sponges, corals, and sea squirts are considerably different to the surrounding reefs. For example the number of species of hard corals and soft corals, recorded on the wreck were low although these are common members of the benthic community on local reefs (hard corals - wreck: 5 ; reef: 18;. soft corals - wreck: 9 ; reef: 32; Fig. 23B). As corals are relative recent settlers of the wreck, it is expected that further recruitment will occur over time. Although sponges showed a distinct shift towards larger specimens with more 3-dimensional growth on the wreck since the survey in 2006 (Fig. 5-7; 22), species richness of encrusting sponges was still high, whereas massive sponges were clearly more dominant in the natural reef sites. In contrast, ascidian species richness was higher at the wreck in comparison to the reef sites. Within the group of Echinodermata similarity in species composition between the wreck and the natural environment was low (Table 2). Furthermore, the absence of starfish on the wreck was remarkable, as species richness at the reef was comparatively high (7 species).

It is expected that a further succession will occur over time through recruitment of new species and taxa, competition for space, light etc., and species composition on the wreck will become more representative of the natural reefs. Furthermore, given the changes in recruitment to the wreck it is predicted that species diversity will further increase over time, but the exact trajectories, interactions and responses to environmental factors cannot be extrapolated and require ongoing monitoring of the wreck. Such monitoring requires censuses at biennual intervals and repeated over at least 10 years.

3.2. Fish

3.2.1 Spatial and temporal changes in fish diversity

Numerous additional fish species have been found on the wreck in 2008 since the original surveys of 2006. However, the total number of species recorded during census has remained relatively constant. A cumulative total of 192 species have now been recorded on the wreck from 2006 to 2008 (Table 3). This total includes 139 species from surveys conducted in November 2008, 111 from November 2006, and 133 from July 2006. The results show small net increase in species richness of resident fishes since 2006. However , the composition of the fauna continues to evolve resulting from competitive pressures between fishes, as well as changes in available habitat.

Since 2006 there has been considerable succession, however new colonisers were outnumbered by emigrants, indicating that fish communities may be approaching a more mature phase. In the most recent surveys of 2008 / 2009, 40 of the 139 species had not been recorded in 2006, but 52 of those found during 2006 were not recorded in 2008. Discounting possible chance encounters, where species with fewer than six recorded individuals are excluded, there were 10 additional species occurring in significant numbers in 2008, counterbalanced by 22 species that were no longer present. Families with representatives most prominently new to the wreck included serranids (several rock cods and the basslet, *Pseudanthias rubrizonatus*), pempherids (bullseyes), labrids (wrasses, especially *Leptojulis cyanopleura* and *Suezichthys gracilis*) and gobiids (gobies; Fig. 15-18). Families with species conspicuously present on the wreck initially, but now absent include priacanthids (bigeyes), some carangids (trevallies), pomacentrids (Gulf Damsel, *Pristotis* *obtusirostris* and most Sergeants, *Abudefduf* spp.), an acanthurid (Yellowmask Surgeonfish, *Acanthurus xanthopterus*) and most monacanthids (leatherjackets).

Among the six largest families, the most notable changes from 2006 to 2008 were an increase in the species of serranids from 7 to 11 and a decrease in the species of carangids from 13 to 9 (Fig. 24B). Notable on the foredeck during the most recent surveys were several individuals of the two anemonefishes, *Amphiprion akindynos* and *A. latezonatus*, both of which have occupied anemones growing on the deck area subsequent to the 2006 surveys.

There are clear examples of changes in species composition on the wreck. Opportunists such as Gulf Damsels, *Pristotis obtusirostris* and Dusky Leatherjackets, *Paramonacanthus otisensis* were quick to colonize the new habitat in 2006, but subsequently moved on as competitors established and habitats matured. Some zooplankton feeders, such as the bigeyes, *Priacanthus hamrur* and *P. macracanthus* were present in huge numbers throughout 2006, but completely disappeared by 2008. A wide range of carangid (trevally, kingfish and scad) species aggregated around the wreck during its early stages to capitalise on abundant new food resources provided by prolific juvenile recruits and monospecific apogonid (cardinalfish) shoals, however as this resource declined, a significant number of species of this family emigrated from the wreck and were not recorded in 2008. Two pelagic species very common during early stages of the wreck, the Yellowmask Surgeonfish, *Acanthurus xanthopterus* (an algal grazer) and the Unicorn Leatherjacket, *Aluterus monoceros* (a feeder on soft invertebrates), appear to have been excluded by competitive pressures resulting from changes in the availability of their preferred food resources.

The deck area of the wreck was consistently the most favoured habitat for fishes (Table 3; Fig. 24A). Overall, 69 percent (or 133 species) of the 192 found on the wreck were recorded in this area, while individual recordings comprised 59 to 71 percent between 2006 and 2008. In 2008, diversity of most of the largest fish families, especially the pomacentrids (damselfishes), labrids (wrasses) and lutjanids (tropical snappers) was significantly greater around the deck than in the other areas (Fig. 24A). The next most speciose sector of the wreck overall was the lower hull (61%, or 118 species), followed by the superstructure (53%, or 101 species). The sector with the least diversity overall was clearly the internal areas, with 40 percent of the fauna, or 76 species. The internal areas did, however, support a greater diversity of chaetodontids (butterflyfishes) than other sectors (Fig. 24A). By 2008, differences in diversity of the top six families between the superstructure, internal areas, and lower hull had become less pronounced than previously.

The superstructure held the most consistent number of species across the three recording events from 2006 to 2008, with nominal counts of 55, followed by 68 and 58. However, this sector varied from the most to the least speciose on the wreck (61 to 41 percent of the total fauna), due to significant fluctuations in numbers of species in other areas (decks and lower hull). It seems species occurring around the superstructure may be less prone to periodic emigration from the wreck, than are species found around the decks and lower hull. Carangids (trevallies and scads), lutjanids (tropical snappers and fusiliers) and haemulids (sweelips) have displayed a tendency to vacate the latter areas, with a number of species present in July 2006, absent in November 2006, but present again in November 2008. In the most recent recordings, the superstructure was the least diverse of all sectors, comprising only 42 percent of species recorded. Characteristics of the habitat available on the superstructure remained relatively consistent over the survey period, with encrusting invertebrate communities on the mostly narrow vertical surfaces there more heavily exposed to swell, surge, tidal current and fish feeding activity. Habitat in other sectors varied more over time, and changes probably provided more distinct cues for fish movement to and from the wreck.

The species count for the internal areas was the most variable as a proportion of that recorded for the wreck as a whole, with an increase over time, culminating in a 22% variation between the initial and most recent recording events (variation for other sectors was up to 20% for the superstructure, 18% for lower hull, and 12% for the decks). Although numbers of species varied considerably from one recording event to another for most sectors of the wreck, the internal area was the only sector of the wreck to record a significant increase in species numbers from 2006 to 2008, albeit from a low base. Only 30 species were recorded there in July 2006, 34 in November 2006, but 63 in November 2008. Habitat formed by invertebrate communities was slower to develop and mature in internal areas than it was in external sectors of the wreck, leading to a corresponding response by many fish species. Colonisation of the internal areas, although muted relative to other sectors with only 76 species recorded overall, was broad-based, with small increases across numerous families.

Other notable events spanning the period from the sinking of the wreck to the present were recruitment and maturation observed for some species. In particular, there were interesting observations on the two most common serranid fishes (Purple Rock Cod, *Epinephelus cyanopodus* and Maori Rock Cod, *E. undulostriatus*). No medium to large-sized individuals of these or any other serranid (*Epinephelus* spp.) were recorded in the initial surveys. However numerous small juveniles were observed. Follow up surveys in November 2006 recorded a mix of somewhat larger juveniles and subadults of these species. In November 2008, no juveniles of these species were observed, but similar numbers were recorded as adults. Additional recruitment of juveniles more recently was probably impeded by predation from established individuals. The early recruitment of larvae or small juveniles to the wreck, followed by apparent site fidelity and retention of adults, seems to indicate the sites potential to support juveniles through to maturity, rather than migration of adults to the wreck at the expense of nearby natural reef areas.

In parallel with this, another serranid, the Oval Rock Cod, *Triso dermopterus*, had a contrasting history on the site. Mature individuals were common on the site during the first survey, but numbers have progressively declined, and during the most recent surveys only few individuals were recorded. Oval Rockcod are a moderate-sized, mobile species, known to favour wrecks and other artificially created habitats. Their original abundance on the site would have been favoured by the lack of other large predatory serranids. The gradual reduction in their numbers over the following period is likely to have been, at least in part, a response to increasing competitive pressure from the two forementioned *Epinephelus* species, as they approached maturity.

The population of Snapper, *Pagrus auratus* on the site has also experienced progression in size classes. During 2006 only juveniles and subadults were noted, but in 2008 there were also significant numbers of large adults.

3.2.2. Temporal changes in fish abundance

The wreck continues to hold large numbers of a wide variety of fishes, representing an impressive biomass. Trends in abundance have generally been steady, or one order of magnitude up or down (Table 3). Broadly, some predators increased, omnivores recorded both increases and declines, while planktivores and herbivores mostly had modest declines. Wholesale shifts in abundance, where species were newly recorded in the most recent survey, or had emigrated entirely after being present in the initial or subsequent surveys, are discussed above under changes in biodiversity. Other changes in abundance included the following:

- Serranidae (rock cods) - steady, except for *Triso dermopterus*, which declined markedly.
- Lutjanidae (tropical snappers) - *Lutjanus quinquelineatus*, *L. russelli* and *L. vitta* showed a increase in numbers, while those of *L. sebae* decreased more significantly.
- Sparidae (bream, snapper, tarwhine) - all three species increased in numbers.
- Mullidae (goatfishes) - *Parupeneus spilurus* decreased in numbers.
- Pempheridae (bullseyes) - two species were new in the recent survey, and one increased in numbers.
- Chaetodontidae (butterflyfishes) - decline in *Chelmonops truncatus* and *Heniochus acuminatus*.
- Pomacanthidae (angelfishes) - progressive increases in *Chaetodontoplus meredithi*.
- Pomacentridae (damselfishes) - *Pristotis obtusirostris* disappeared after being very common, there were declines in the large populations of *Chromis nitida* and *Neopomacentrus bankieri,* but a significant increase in *Abudefduf bengalensis*.
- Siganidae (rabbitfishes) - decline from initially high levels.
- Acanthuridae (surgeonfishes) - decline in several species.

3.2.3 Comparison of fish species composition and abundance between the wreck and adjacent natural reefs

To compare diversity and abundance of fishes on the wreck with that on adjacent natural reefs, the results of surveys on the wreck were contrasted against two sites on nearby natural reefs that most closely approximated the structural complexity of the wreck (Fig. 1). The natural reef sites selected were not as topographically prominent as the wreck, but had some steep vertical walls, ledges, overhangs, large boulders, crevices and caves that would provide similar opportunities for shelter and concealment of fishes. There was rubble and sand substrate adjacent to the foot of the reef, similar to that existing at the wreck, however the invertebrate communities were well developed and mature, with extensive hard and soft coral growth.

Surveys on the natural reef in summer/ early autumn 2009 recorded a level of diversity nominally almost identical to that found cumulatively for the wreck between 2006 and 2008 (Table 4). One hundred and ninety-three species of 40 families were found on the reefs, versus 192 species of 47 families on the wreck. However, when resident species during each survey event were considered separately (as opposed to cumulatively since 2006), the species count for the reef outstrips that for the wreck by a large margin (39-74 percent, average of 51 percent per survey).

Although the overall number of species was similar on the wreck and the reef, species composition varied significantly. Eighty-six species were exclusively recorded on the wreck, while 87 species were found on the reef, but not on the wreck. Of the six most speciose families recorded in the area, Chaetodontidae (butterflyfishes), Pomacentridae (damselfishes) and Labridae (wrasses) were much more diverse on the reefs, Carangidae (trevallies and scads) and Lutjanidae (tropical snappers and fusiliers) were clearly more diverse on the wreck, while Serranidae (rock cods and basslets) had similar numbers of species in both areas (Fig. 24B). Of the smaller families, Synodontidae (lizardfishes), Holocentridae (squirrelfishes), Nemipteridae (threadfin and monocle bream), Mullidae (goatfishes) and Pomacanthidae (angelfishes) (Fig. 19-21) were more diverse on the reefs.

Biomass on the wreck was significantly greater than that in similar-sized areas on the natural reef, being composed of greater numbers of generally larger fish. Relative abundance levels of many families however varied considerably between wreck and reef sites. Of those families with species common to both sites, the following patterns were recorded:

- Serranidae – *Epinephelus coioides*, *E. cyanopodus*, *E. undulostriatus* and *Pseudanthias spp.* were more abundant on the wreck, while *Diploprion bifasciatum*, *Epinephelus fasciatus* and *Plectropoma leopardus* were more abundant on the reefs. P. *leopardus* is an ambush predator that often launches attacks from beneath coral heads to feed on species that aggregate above these structures,

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hence its apparent preference for reef habitat.

- Apogonidae - species that school in large numbers in sheltered environments, such as *Apogon capricornis* and *A. flavus* were more prevalent in the wreck, while most other species were more common on the reefs.
- Carangidae – the wreck has proved to be effective in aggregating various carangids in moderate to large numbers, while the few species that were recorded on the reef were found in relatively low numbers.
- Lutjanidae – all species, including both the mainly piscivorous *Lutjanus* spp. and the planktivorous *Pterocaesio* spp., were equally or more abundant on the wreck.
- Sparidae – all three species were significantly more abundant on the wreck, possibly due to the greater density of molluscs, a favoured dietary item.
- Lethrinidae – *Lethrinus laticaudis* and *L. nebulosus* were most common on the wreck, possibly due to relatively high densities of molluscan species, which are a common dietary component.
- Mullidae - *Parupeneus spilurus*, the only mullid common to both sites, was more abundant on the wreck.
- Chaetodontidae – the schooling planktivorous *Heniochus acuminatus* and generalist feeders *Chaetodon guentheri* and *C. kleini* were equally or more abundant on the wreck, whereas others such as *C. rainfordi* and *C. trifascialis*, taht are more specialised on sessile invertebrates were either exclusive to or more abundant on reef habitats.
- Kyphosidae – *Microcanthus strigatus* and *Scorpis lineolata* were more common on the wreck.
- Cheilodactylidae – *Cheilodactylus vestitus* was most common on the wreck.
- Labridae – the Common Cleanerfish, *Labroides dimidiatus* was more abundant on the wreck, due to the preponderance of large host fishes; *Suezichthys gracilis* seemed to prefer the slightly looser rubbly sand around the fringes of the wreck than that near the reefs; *Leptojulis cyanopleura, Pseudolabrus guentheri* and *Thalassoma* spp. were about equally represented between the sites; all other labrids were more abundant on the reefs, with their specialist feeding habits being better suited to the wider diversity of benthic invertebrates available on the reefs.
- Pomacentridae – *Chromis nitida, Dascyllus trimaculatus, Neopomacentrus bankieri* and *Parma* spp. were about equally or more abundant on the wreck, while other pomacentrids were more common on the reefs due to their reliance on invertebrate communities more diverse than on the wreck.
- Acanthuridae – *Acanthurus mata*, a plankton feeder, was more abundant around the wreck, while the algal grazer *Acanthurus dussumieri* was more common on the reefs.

Overall, large piscivores, molluscivores, omnivores and planktivores were more abundant on the wreck, while groups with species more specialised on benthic invertebrates (especially corals) were clearly more common on the richer reef environment.

3.3. Encrusting biota ('fouling assemblages')

The diversity of epifaunal invertebrates continued to increase on the wreck, with a large proportion of the surface of the ex-HMAS *Brisbane* covered by a range of encrusting epifauna and flora (Appendix 1). A total of 48 different epifaunal taxa were identified across 235 photo quadrats; Porifera (sponges) were the most speciose group with 22 taxa, followed by corals (15 taxa), ascidians (sea squirts; 14 taxa), soft corals (8 taxa), bryozoans (8 taxa), bivalves (6 taxa), polychaetes (3 taxa) and Cirripedia (barnacles; 2 taxa). Bryozoans and Porifera dominated the cover of vertical surfaces, particularly at 18 m depth. On the horizontal surfaces, the dominant groups were bryozoans, corals and bivalves. More species occurred on vertical than on horizontal surfaces. The highest species richness (50) was recorded on vertical surfaces of the natural reef, while the least number (5) was found on horizontal surfaces on the wreck in 2006 (Fig. 25A).

The factors examined here are depth, exposure (exposed vs. sheltered), orientation (vertical vs. horizontal), and natural vs. artificial habitats (i.e. wreck vs. reef).

3.3.1. Variation within fouling assemblages with exposure (Starboard vs. Port sides) and depth

In 2006, we found that there was very little difference in the cover of sessile fauna between the starboard (exposed) and port (sheltered) sides of the wreck, however the species composition was different (Schlacher-Hoenlinger *et al.,* 2006). These differences were likely due to the predominant southeast direction of currents, swell and wave action, which would influence the larval supply and the degree of exposure to physical disturbance between the port and starboard sides of the artificial reef, and therefore influence the recruitment, survival, and composition of assemblages found there (Cummings, 1994; Svane & Petersen, 2001).

In 2008 the composition of epifaunal assemblages differed between the starboard and port sides of the wreck at both 12 and18 m depth (Fig. 26; ANOSIM Exposure R = 0.18, $p < 0.001$; Depth = 0.24, $p < 0.001$). The difference between depths was due largely to the reduced cover of the bryozoan, *Celleporaria* sp. 1, and increased cover of the sponge, *Batzella* sp. 4217. Differences between port and starboard sides of the wreck were due to an almost three-fold increase in the coverage of *Celleporaria* sp. 1 from the starboard (9.3%) to port (24.6%) side of the wreck. The cover of *Balanus* sp. 1 also increased from starboard (3%) to port (6.8%) sides of the wreck. These differences in the coverage of *Celleporaria* sp. 1, *Batzella* sp. 4217 and *Balanus* sp. 1 accounted for more than 55% of the biotic differences between the two depth strata, and between the port and starboard sides of the wreck (Fig. 26; SIMPER).

The cover of all epifaunal taxa was lower on the starboard side (33%) than on the port side (40%) of the wreck (Fig. 27A; Table 5, ANOVA). Depth did not appear to influence total cover (Fig.

27A; Table 5, ANOVA). Despite the large differences in cover of epifauna between sides of the wreck, there were only small differences in species richness between the port and starboard side; that is, more species per quadrat were recorded at 18 m (Fig. 27B; Table 5, ANOVA).

The pattern of distribution for some taxa between the exposed and sheltered side of the wreck changed significantly over time. In 2006 bryozoans (primarily *Schizoporella* sp. 1) were more abundant on the starboard side at 18 m than elsewhere. Conversely, in 2008 bryozoans (primarily *Celleporaria* sp. 1) covered more space on the port side at 12 m (Fig. 27C; Table 5 & 6, ANOVA). In 2008, the cover of sponges was more than 3 times greater at 18 m than at 12 m depth (Fig. 27C). In 2006, a similar depth effect was seen for sponges, however this group covered more space on the starboard than port sides of the wreck (Schlacher-Hoenlinger *et al.,* 2006; Walker *et al.*, 2007). By contrast, there was no difference in cover between exposures in 2008 (Fig. 27C).

Variation in the cover of species between depths and exposures on the wreck may be due to a range of effects associated with larval supply and growth (Cummings, 1994; Svane & Petersen, 2001), such as larval stratification within the water column (Grosberg 1982), increased larval supply (Baynes & Szmant 1989; Cummings1994; Svane & Petersen 2001) and food availability (Lesser et al. 1994) caused by the predominant direction of water currents that impinge mostly on the starboard side. Survivorship may also differ between the two sides of the wreck because of hydrological factors such as the direction of storms, prevailing water currents, and gravel scouring (Cummings, 1994; Svane & Petersen, 2001). Larvae of a number of colonial invertebrates such as bryozoans, sponges and ascidians brood their larvae, resulting in a short dispersal distance (e.g. sponges do not have a pelagic “lechithotrophic” larva; Uriz *et al*., 1998; Maldonado & Bergquist, 2002; Maldonado, 2006).

Invertebrate larvae also have limited time and resources in which to respond to settlement cues from the surrounding environment (Marshall *et al*., 2003). Larvae, carried in the predominant southeast water currents, may settle when they first reach an appropriate settlement surface (the starboard side of the wreck), potentially decreasing the larval supply to the port side of the wreck. However, if the availability of space is reduced, through pre-emption of space, then larvae may remain in the water column for longer periods until a more favorable settlement surface is found (Marshall *et al*., 2003). Likewise, different sides of the wreck may have different source populations, with larval supply and recruitment depending on the direction of prevailing currents. More work is required to understand the importance of larval supply, settlement and recruitment for sessile encrusting organisms like bryozoans and sponges on this wreck, and to understand the levels of connectivity between this artificial reefs and surrounding populations on natural reefs. Also more work is necessary to determine whether the patterns of sessile species shown are due to variation in larval supply and recruitment, physical disturbance or competition from photophilic organisms, such as algae.

3.3.2. Variation within fouling assemblages with orientation: vertical vs. horizontal surfaces

In 2006 we compared vertical surfaces on the port and starboard sides of the wreck with horizontal surfaces on the main and upper decks of the wreck. We found that there was a substantial difference in the composition and cover of epifaunal assemblages between horizontal and vertical surfaces at both 12 and 18 m depth (ANOSIM, $R = 0.92$, $p = 0.002$); in this instance, three species (*Balanus* sp.1, *Schizoporella* sp.1, *Pinctada maculata*) accounted for more than 80% of the biotic differences between the horizontal and vertical surfaces and different depths (Schlacher-Hoenlinger *et al.*, 2006). Overall, there were large differences in cover and species richness of sessile fauna between vertical and horizontal surfaces: cover of fauna decreased by 50% to 70% on the horizontal surfaces and 17 fewer species were found there (Schlacher-Hoenlinger *et al.,* 2006; Walker *et al.,* 2007).

A similar pattern was evident in 2008: the species composition of epifaunal assemblages differed strongly between horizontal and vertical surfaces (Fig. 28; Table 7, ANOSIM Orientation $R = 0.54$, $p < 0.001$; Depth $R = 0.22$, $p < 0.001$). Differences in community structure were largely due to a significantly higher cover of fauna (i.e. *Celleporaria* sp. 1, *Batzella* sp. 4217, *Balanus* sp.1, and *Pinctada maculata*) on the vertical surfaces; these taxa contributed more than 60% to the biotic differences between surface orientations (SIMPER).

The density and percent cover of epifauna on vertical surfaces was substantially higher than that found on horizontal surfaces yet there remained very little difference between the 12 and 18 m depth contours (Fig. 29A & B; Table 7, ANOVA). Overall, the cover of taxa, particularly on vertical surfaces, had declined to < 40% in 2008 (Fig. 29A). The decline was due largely to decreased cover of the once dominant bivalves and barnacles on the wreck. While these species were still abundant (i.e. high biomass), they occupied much less space than in 2006.

Overall, the cover of many taxa was reduced on the horizontal surfaces in both years surveyed (Fig. 29C; Schlacher-Hoenlinger *et al.,* 2006; Walker *et al.*, 2007). However, the relative dominance of particular species in 2006 had changed over time, with barnacles, bivalves and bryozoans dominating assemblages in 2006 (Schlacher-Hoenlinger *et al.,* 2006; Walker *et al.*, 2007), and bryozoans and sponges dominating assemblages in 2008. The cover of bryozoans (primarily *Celleporaria* sp. 1) increased more than 4 times from horizontal to vertical, especially at 12 m depth (Fig. 29C; Table 8, ANOVA). The cover of sponges also increased between horizontal and vertical surfaces, with the greatest magnitude of change occurring at 18 m depth (Fig. 29C; Table 8, ANOVA). In contrast, the cover of bivalves and barnacles declined substantially to less than 3% in 2008, and there was no difference among depths or orientations (Fig. 29C;

Table 8, ANOVA). In contrast, barnacles covered more space on vertical than horizontal surfaces at both 12 m and 18 m, and were more than twice as abundant on horizontal surfaces at 12 m, than at 18 m depth (Fig. 29C; Table 8 ANOVA).

The high cover and dominance of epifaunal assemblages by the pioneer species *P. maculata* and *Balanus* sp. 1 in 2006 may have been caused by a pulsed recruitment event, followed by a substantial decline in abundance caused by reduced survival. The decline in cover on horizontal surfaces may be due to increased physical damage or smothering by sand (Kay & Keough 1981; Baynes & Szmant 1989; Badalamenti et al. 2002; Irving & Connell 2002), rather than biotic interactions such as predation or competition, given the high proportion of space covered by sand. We found that sediment did not accumulate on the vertical surfaces of the wreck but covered over 90% of the horizontal surfaces. It is thus likely that the difference in sessile invertebrate coverage between horizontal and vertical surfaces may be due to smothering by sediment on the horizontal surfaces (Baynes & Szmant 1989; Irving & Connell 2002) or due to differences in the settlement preferences of some species. A high percentage of shell pieces were found on the horizontal surfaces (primarily from *P. maculata*), which may indicate at least some level of predation by fish on these species.

A number of small hard and soft coral colonies had colonized the wreck, particularly on the horizontal surfaces of the wreck, but also on the vertical surfaces (Fig. 8-9). Hard and soft corals are more common on natural reefs surrounding the reef, and may be less palatable to predators (such as fish) found on the wreck (Schlacher-Hoenlinger *et al.,* 2006; this report). On horizontal surfaces, hard and soft coral grew up off the surface (erect growth form) of the wreck and may therefore have reduced susceptibility to smothering from sand.

3.3.3. Variation within fouling assemblages between natural and artificial reefs

We compared the sessile assemblages from two different orientations on the artificial reef at 18 m depth with the similarly orientated assemblages on two natural reefs in the vicinity of the wreck, to determine whether the composition of epifaunal assemblages on the artificial reef (one and three years after scuttling) became similar to that found on the nearby natural reefs, and therefore representative of subtidal reefs on the area (Walker *et al.,* 2007).

Shifts in epifaunal assemblage structure between the artificial and natural reef were more pronounced for fauna of vertical surfaces; conversely, communities on horizontal surfaces diverged much less between the artificial reef and the natural reefs (ANOSIM: Horizontal, Global $R = 0.46$, $p < 0.001$; Vertical, Global $R = 0.73$, $p < 0.001$). There are indications of community change on the wreck where the trajectory is towards greater similarity with natural reef communities over time; these changes are indicated for both horizontal and vertical surfaces (Table 9). Nevertheless, three years after the scuttling of the HMAS

Brisbane, the structure of epifaunal assemblages on the artificial reef remains quite different from that found on adjacent natural reefs.

The average species density of assemblages sampled from horizontal surfaces on natural reefs was almost double that found at sites on the wreck (Fig. 31B; Table 10, ANOVA). However, this increase in the density of taxa corresponded to a very large increase in the cover of sessile fauna on natural reefs compared with sites on the artificial reef (Fig. 31A), due to the presence of large, established coral and soft coral colonies that covered most of the available horizontal space on the natural reefs sampled (Fig. 31C). These species, while present on the artificial reef during the 2008 survey, covered less than 4% of the available surface area.

While the total number of species found on the vertical surfaces on natural reefs continues to be greater than on the artificial reef (Fig. 25), benthic cover is not (Fig. 31B; Table 10, ANOVA). Thus, the artificial reef supports abundant epifaunal assemblages, but these are composed of fewer species overall than natural reefs.

Similar to other artificial reefs (Svane & Petersen, 2001), scuttling the ex-HMAS *Brisbane* has provided an increase in the availability and suitability of hard substrata, and consequently provided appropriate habitat to support diverse fouling assemblages. Enhancing biodiversity on the artificial reefs may support a range of mobile invertebrates and fish (see earlier sections 1 & 2), through the provision of increased food resources, increased feeding efficiency and structural protection from predators (Bohnsack 1989; Svane & Petersen, 2001). A comparison of colonisation between natural and artificial reefs is important to assess the degree of overlap in community composition, levels of productivity and ecosystem function, and therefore assess the effectiveness of the artificial reef (Carr & Hickson 1997; Svane & Petersen, 2001). Despite differences in the biological history and in substrate heterogeneity between natural and artificial reefs (Carr & Hickson 1997; Glasby & Connell 2001; Svane & Petersen, 2001; Walker *et al*., 2007), we predict that as colonisation of the artificial reef proceeds, the epifaunal assemblages will become more similar to those on natural reefs, especially with an increase in the proportion of large, longer-lived species, such as hard and soft corals, that currently cover much of the available area on natural reefs.

4. RECOMMENDATIONS

A number of factors contribute towards making the ex-HMAS *Brisbane* an important asset of South-East Queensland:

(1) considerable investment by the State Government in creating the artificial reef of the ex-HMAS *Brisbane*,

(2) ongoing commitment of resources by EPA/QPWS in maintaining and enforcing the conservation area around the wreck,

(3) measurable benefits for the local/regional tourism industry from the wreck, particularly through dive tourism, and

(4) high-profile public interest in the ship and cultural heritage values associated with an ex Australian navy ship. Given the importance of the wreck for the above reasons, the ecological features of the site need to be more comprehensively assessed to complement the range of socio-economic values that are already associated with the wreck.

This report shows conclusively that the wreck has already become an artificial reef that can support an impressive range of biodiversity. Furthermore it may have the potential to contribute significantly towards the overall diversity of the nearshore zone in the region.

As further changes in biodiversity over time are expected, a series of future, scientific investigations on the biological processes on the wreck are required.

RECOMMENDATION 1

Colonisation of the wreck

Establish and resource continuing medium-term (e.g. biennial surveys over the next ten years) scientific monitoring programme that documents the nature and dynamics of biological colonisation.

In addition to its socio-economic value as a highly attractive dive destination, the wreck is predicted to play a significant role as a valuable habitat addition to the nearshore marine zone, supporting a diverse assemblage of invertebrates and fish.

The baseline survey in 2006 represented a basic reference point against which future colonisation of the wreck by marine life could be benchmarked. This survey in 2008/2009 indicated a continual biotic community change on the wrecks with a trend towards greater similarity between natural and artificial reef communities over time.

The current state of colonisation of the wreck may still represent an early stage in the ecological succession of the wreck-associated assemblages, since this is only the third year since scuttling. Biodiversity of the wreck fauna may further increase over time. Although this prediction is based on experience from artificial reefs and wreck in other locations, the actual trajectories and dynamics of any further colonisation on the ex-HMAS *Brisbane* can only be determined through continued ecological monitoring of the wreck-fauna. Thus, a continued monitoring programme needs to be funded to quantify the nature and dynamics of biological colonisation processes on the wreck over the next decade, with comprehensive surveys done at least every two years.

RECOMMENDATION 2

Wrecks as essential habitats

Design, establish and finance studies that document ecological values of the wreck in terms of creating essential habitats that enhance the biodiversity of the marine ecosystem complex in the vicinity of the wreck site.

The wreck now holds a resident population of mature commercially and recreationally valuable fishes that could easily be targeted and largely removed by fishers, if it were not for the protected status of the site. These fishes undoubtedly enhance the value of the wreck as a SCUBA-diving destination and help to promote its future as a significant regional underwater tourism drawcard. It is therefore imperative that current protection and enforcement measures are rigorously maintained for the site.

There is scant evidence to date that fish assemblages on the wreck have matured to the point where further change is unlikely. Long-term monitoring of species composition and abundance is recommended to document future trends and to help in evaluating the role and value of wrecks as additional habitat for fishes off the Sunshine Coast.

Significant differences were identified between the wreck and adjacent natural reefs in terms of diversity, species richness and abundance of their resident fishes, corals, and other benthic fauna. Monitoring of the wreck and natural reefs in tandem on the same seasonal cycle should be conducted to obtain replicate datasets over the longer term. This will assist in establishing whether current community structure of the wreck has stabilised or continues to evolve, and whether its composition moves closer to that on the natural reefs over time. This information would be valuable in determining whether wrecks provide important new self-sustaining habitat for fishes and invertebrates in their own right, as opposed to acting simply as aggregating devices that only attract fishes from nearby natural habitats.

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sp. 2 h) *Symplegma rubra.*

Fig. 15. Fish recorded from the ex-HMAS Brisbane: a) *Lutjanus argentimaculatus* (Mangrove Jack)b) *Epinephelus undulostriatus* (Maori Rockcod) c) *Lethrinus laticaudus* (Grass Emperor) d) *Plectorhinchus flavomaculatus* (Goldspotted Sweetlips) *e) Lutjanus sebae* (Red Emperor) f) *Triso dermopterus* (Oval Rockcod) and two Heniochus acuminatus (Longfin Bannerfish) g) *Bodianus frenchii* (*Foxfis*h) h)*Sufflamen bursa* (Pallid Triggerfish).

Fig. 16. Fish recorded from the ex-HMAS Brisbane: a) *Eviota albolineata* (Whitelined Eviota)b) *Eviota prasites* (Hairfin Eviota) c & d) *Norfolkia squamiceps* (Scalyhead Threefin) e) *Scorpaenopsis venosa* (Raggy Scorpionfish) f) *Dendrochirus zebra* (Zebra Lionfish) g) *Pempheris affinis* (Blacktip Bullseye) h) *Rhabdamia gracilis (Slender Cardinalfish).*

Fig. 17. Fish recorded from the ex-HMAS Brisbane: a) *Abudefduf bengalensis* (Bengal Sergeant) and b) *Parma oligolepis* (Bigscale Scalyfin) guarding their eggs c) *Ostracion cubicus* (Yellow Boxfish) d) *Amphiprion akindynos* juvenile (Barrier Reef Anemonefish) e) *Hypoplectrodes maccullochi* (Halfbanded Seaperch) f) *Pseudanthias rubrizonatus* (Lilac-tip Basslet) g) *Arothron stellatus* (Starry Puffer) h) *Lutjanus vitta.* (Brownstripe Snapper).

Fig. 18. Fish recorded from the ex-HMAS Brisbane: a) *Carangoides gymnostethus* (Bludger Trevally) b) *Taeniura meyeni* (Blotched Fantail Ray) c) *Epinephelus lanceolatus* (Queensland Groper) d) *Rhynchobatus australiae* (Whitespotted Guitarfish) e) *Pagrus auratus* (Snapper) f) *Naso annulatus* (Ringtail Unicornfish) g) *Dicotylichthys punctulatus* (Threebar Porcupinefish) h) *Epinephelus coioides* (Goldspotted Rockcod).

Fig. 19. Fish species recorded on the reef, but not or only rarely recorded from the wreck: a) *Choerodon fasciatus* (Harlequin Tuskfisk) b) *Amphiprion akindynos* (Barrier Reef Anemonefish) c) *Sargocentron rubrum* (Red Squirrelfish) d) *Amblyeleotris wheeleri* (Burgundy Shrimpgoby) e) *Sargocentron melanospilos* (Blackspot Squirrelfish) f) *Chaetodon rainfordi* g) *Archamia leai* (Lea's Cardinalfish) h) *Amblyglyphidodon curacao* (Staghorn Damsel).

Fig. 20. Fish species recorded on the reef, but not or only rarely recorded from the wreck: a) *Crossosalarias macrospilos* (Triplespot Blenny) b) *Macropharyngodon choati* (Choat's Wrasse) c) *Stethojulis interrupta* (Brokenline Wrasse) d) *Pomacentrus bankanensis* (Speckled Damsel) e) *Coris aurilineata* (Goldlined Wrasse) f) *Ogilbyina novaehollandiae* (Multicolour Dottyback) g) *Coris batuensis* (Variegated Wrasse) h) *Pentapodus aureofasciatus* juvenile (Yellowstripe Threadfin Bream).

Fig. 21. Fish species recorded on the reef, but not or only rarely recorded from the wreck: a) *Dascyllus reticulatus* (Headband Humbug) b) *Chaetodon trifascialis* (Chevron Butterflyfish) c) *Pomacentrus amboinensis* (Ambon Damsel) d) *Valenciennea strigata* (Blueband Glidergoby) e) *Chrysiptera talboti* (Talbot's Demoiselle) f) *Macropharyngodon meleagris* (Leopard Wrasse) g) *Pempheris ypsilychnus* (Ypsilon Bullseye) h) *Oxymonacanthus longirostris* (Harlequin Filefish).

Fig. 22. Sessile invertebrate assemblages on the wreck at a & b) vertical surfaces at 12 metres; c & d) vertical surfaces at 18 metres e & f)horizontal surfaces at 12 metres; g & h) horizontal surfaces at 18 metres.

Fig. 23. Comparison of the number of species based on a Rapid Ecological Assessment technique (REA) between: a) different parts of the wreck, and b) the wreck in 2006 and 2008 and the adjoining natural reef in 2008.

Fig. 24. a) Number of species of the six most speciose fish families, according to occurrence in the respective sectors of the wreck. b) Number of species of the six most speciose fish families, recorded on the wreck in 2006 and 2008, and on nearby natural reefs in 2008.

Fig. 25. Species accumulation curves for the difference in total species richness of 'fouling communities' among natural and artificial reefs in 2006 and 2008.

Fig. 26. nMDS ordination for the difference between exposures (port - sheltered & starboard - exposed) and depths (12 & 18 m).

Fig. 27.Differences in the: a) percent coverage (mean ± SE) of sessile epifauna; b) species density (mean ± SE number of species per 625 cm2); and c) percent coverage (mean ± SE) of selected taxonomic groups, between exposures (port - sheltered & starboard - exposed) and depths (12 & 18 m).

Fig. 28. nMDS ordination for the difference between surface orientations (horizontal & vertical) and depths (12 & 18 m).

Fig. 29. Differences in the: a) percent coverage (mean ± SE) of sessile epifauna; b) species density (mean ± SE number of species per 625 cm2); and c) percent coverage (mean ± SE) of selected taxonomic groups, between surface orientations (horizontal & vertical) and depths (12 & 18 m).Fig. 30.

Fig. 30. nMDS ordination for the difference in composition of epifaunal assemblages between the artificial reef sampled in 2006 and 2008, and natural reefs sampled in 2008 a) on horizontal and b) vertical surfaces at 18 m depth.

Fig. 31. Differences in the: a) percent coverage (mean ± SE) of sessile epifauna; b) species density (mean ± SE number of species per 625 cm2), and c)images illustrating the difference between epifaunal assemblages on natural and artificial reefs sampled in 2008 on horizontal & vertical surfaces.

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Fig. 1. The Ex-HMAS *Brisbane* Conservation Park diving site and the Inner Gneerings Shoals natural reef diving sites ('The Trench' and 'Hanging Rock'). Map modified from: *Environmental Protection Agency.*