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Key Ecological Processes in Kimberley Benthic Communities: Recruitment and Herbivory

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WAMSI Kimberley Marine Research Program

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WAMSI Kimberley Marine Research Program

Initiated with the support of the State Government as part of the Kimberley Science and Conservation Strategy, the Kimberley Marine Research Program is co-invested by the WAMSI partners to provide regional understanding and baseline knowledge about the Kimberley marine environment. The program has been created in response to the extraordinary, unspoilt wilderness value of the Kimberley and increasing pressure for development in this region. The purpose is to provide science based information to support decision making in relation to the Kimberley marine park network, other conservation activities and future development proposals.

Front cover images (L-R)

Image 1: Satellite image of the Kimberley coastline (Image: Landgate)

Image 2: Bite marks on seagrass from the herbivorous golden-lined rabbitfish *Siganus lineatus* (Image: Mat Vanderklift)

Image 3:Humpback whale breaching (Image: Pam Osborn)

Image 4:Coral recruitment tiles on metal frame deployed at Hal's Pool, one of five locations in Cygnet Bay and the Sunday Island group (Image: AIMS)

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http://data.aims.gov.au/metadataviewer/faces/view.xhtml?uuid=05f33378-b7df-433f-8019-16e9c7eb8620
http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=05f33378-b7df-433f-8019-16e9c7eb8620

Metadata link for CSIRO herbivory subproject:
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Contents

1 Executive Summary

Replenishment and herbivory fundamentally underlie the ongoing health of coastal marine ecosystems. Regular recruitment is essential for sustaining populations of fish and invertebrates, whilst herbivory transfers energy from primary consumers to higher trophic levels and inhibits overgrowth of reefs by fleshy macroalgae. This project aimed to better understand these ecological processes in the Kimberley region by quantifying when, where and how coral and fish replenishment takes place and who is responsible for the bulk of grazing on primary production (seagrass and algae) in coastal marine areas. Recruitment studies focused on hard corals, as they provide habitat for millions of species but their long-term persistence is threatened by climate change, and teleost fish, which are of ecological, cultural and commercial value. Herbivory studies focused on fish and turtles, which are prominent feeders of seagrass and algae in the tropics and are culturally significant to indigenous people throughout the Kimberley.

Our studies were around Cygnet Bay and the Sunday Island group which experiences tidal fluctuations of up 12m and is typical of the West of the Kimberley. The area is remote, although small local communities and industry (e.g. pearling) are present and are reliant on the ecosystem services provided by the ocean, emphasizing the value of understanding key processes in the area. An Indigenous Protected Area was declared in 2013 and management of the IPA by the Bardi Jawi Rangers is outlined in the Bardi Jawi Healthy Country Management Plan.

This report is divided into three stand-alone sub-projects: fish recruitment, coral recruitment and herbivory. The major findings from each of these sub-projects are outlined below.

1.1 Fish recruitment:

Our research remit was to develop techniques suitable to quantify juvenile fish recruitment in the challenging macro tidal conditions of the Kimberley (how); provide baseline levels of abundance and diversity of juvenile fish across a range of representative Kimberley marine habitats (how many), identify the seasonal timing of fish recruitment (when); identify important juvenile fish nursery grounds or habitats (where) and provide advice on relevant sites as a basis for any future monitoring. In collaboration with the Bardi Jawi Rangers and the Kimberley Marine Research Station, this research was focused in the Cygnet Bay and the Sunday Island group at the mouth of King Sound in the West Kimberley. In total, a series of eight fish recruitment field trips were completed from March 2015 - March 2016.

Our initial pilot study (March 2015) compared seven separate fish recruitment sampling techniques across six locations which together encompassed four different habitats; inter-tidal pools, seagrass, mangrove and coral reefs. The comparative analyses considered sampling effort, ability to accurately quantify juvenile fish diversity and abundance across a range of habitats, precision and safety. Unbaited stereo remote underwater video (stereo-RUVs) came out as a clear winner among techniques. During this pilot study, it also became clear that tidal current strength and habitat type were critically important variables structuring fish recruitment patterns. To address this, we restricted core sampling to neap tides or 1.5 hours either side of spring high and low tides and added in algal meadows as a fifth habitat.

In total, we recorded 125 species of adult and juvenile fish during surveys. Eleven (9%) of these were observed only as juveniles, 43 (33%) as both juveniles and adults, and 74 (60%) as only adults. Among species, 88% of all recorded juveniles were represented by the top 12 species. Interestingly, many of these are considered as highly valued species to the Bardi Jawi community (e.g. Mangrove jack, Golden-lined rabbitfish, Spanish flag) because of their dietary and/or cultural significance.

Among habitats, mangroves, seagrass and algal habitats were all represented by juvenile fishes from 18-20 species, intertidal pools by 13 and coral reefs by 35 species with only 6% of the species pool observed in all five habitats. A closer look at the distribution of species among habitats revealed very distinct partitioning of nursery grounds. Our analyses showed that mangroves and seagrass areas were critical nursery habitats for many

important species and that many of these species exclusively recruited to these habitats. In comparison, the other three habitats shared a common species pool indicating that any future sampling should concentrate on mangrove, seagrass and, given their increased diversity, coral reef habitats to provide comprehensive coverage of fish recruitment.

Seasonally, fish recruitment was strongest in the wet season (March / April) for most species although there were exceptions. Interestingly, some of the species considered most important to the local indigenous community are species that we identified as having strong year round recruitment providing scientific support for documented traditional Bardi Jawi fishing knowledge and management practices.

Our sampling program provides a blueprint for future monitoring of fish recruitment in the challenging Kimberley marine environment. Here we have established best-practice sampling techniques and provided locations of appropriate monitoring sites for quantifying juvenile fish recruitment across a range of representative habitats to form the basis for future long-term monitoring in the Western Kimberley.

1.2 Coral recruitment

Corals are an essential element of reef ecosystems, providing a structural framework for reef growth, as well as a habitat and food source for many other organisms. For benthic organisms like corals, sexual reproduction and the pelagic larval stage provides an opportunity for genetic mixing of populations and recovery from disturbances. In the inshore Western Kimberley, at Cygnet Bay and the Sunday Island group, reproductive and recruitment patterns for corals have not been previously studied. We modified existing, standardised methods of surveying coral larval supply, by attaching coral settlement plates to frames that enabled their deployment and retrieval from the surface, rather than by SCUBA divers. These frames were specifically designed to withstand the strong currents of the macro-tidal Kimberley environment.

Monthly sampling at 5 locations for a 13 month period allowed us to discern temporal patterns in coral recruitment and identify likely periods of mass spawning. However, extreme water temperatures that persisted through summer and autumn culminated in a coral bleaching event that peaked in March-April, affecting between 30-60% of the community. The bleaching coincided with the predicted mass-spawning period, and reduced rates of recruitment for all corals, particularly for spawning corals. Given the duration and severity of the temperature anomalies, the quantified rates of recruitment are unlikely to reflect those during years without such stress. Nonetheless, the recruitment of *Acropora* peaked in March-April 2016 and to a lesser extent in September-October, at the same time as mass- and multi-specific spawning events were documented on oceanic reefs in the Kimberley and Pilbara to the south. Recruits from the family Pocilloporidae (comprising both brooders and broadcast spawners) and genus *Isopora* were more abundant in the summer months. Additionally, we provide the first definitive evidence of reproductive output and recruitment by corals in family Poritidae over many months throughout the year, supporting anecdotal evidence from reproductive studies at oceanic reefs in the region.

The number and composition of coral recruits differed considerably among the study locations, reinforcing the spatial heterogeneity evident in most studies of biological communities in the Kimberley. Fine-scale spatial heterogeneity also varied as expected among coral groups, with evidence of recruitment variation in brooding corals over distances of less than a few hundred metres, compared with tens of kilometres for groups of spawning corals, which corresponded to genetic evidence from WAMSI Project 1.1.3. Continuation of sampling in future years, applying the methods developed here, would allow a further assessment of spatial and temporal variation in recruitment of corals at inshore Kimberley reefs, and presumably track the recovery of communities to background levels of recruitment following the bleaching disturbance.

1.3 Herbivory

The main aim of this research was to understand the relative importance of direct consumption of seagrass as a proportion of total seagrass production in the Kimberley, to identify the key herbivores, and to understand the relative importance of different primary producers to their diet. Although primary producers occupy a wide

variety of habitats, the primary focus of this study were the seagrass meadows of Tallon Island (Jalan) and Sunday Island (Iwany) located in the Bardi Jawi Indigenous Protected Area. The research used and extended research conducted as part of WAMSI Kimberley Marine Research Program (KMRP) project 2.2.4 (Benthic primary productivity).

We measured higher rates of grazing on seagrass than anywhere else studied in the world — in some locations during some surveys, rates of consumption were more than ten times that of growth. This was particularly pronounced for the seagrass *Thalassia hemprichii* (otherwise known as turtlegrass), for which average consumption was higher than average growth. *Thalassia* is one of the most abundant seagrasses in the terraced lagoons that are characteristic of the Kimberley, and the apparent contradiction of high abundance and high consumption is probably reconciled by a combination of fast growth rates and patchy grazing; indeed rates of consumption of *Thalassia* varied by two orders of magnitude. It is plausible (even likely), that the measured rates of consumption are higher than the long-term averages, which would explain how seagrass can exist and grow in a place with such high rates of herbivory.

In contrast, consumption of the seagrass *Enhalus acoroides* was on average lower than growth. An inference from this finding is that much of its production is probably not consumed by herbivores. We did not set out to study the fate of seagrass production, but it is likely that much leaf biomass for *E. acoroides* is ultimately exported from the meadows as detritus.

There were several species of herbivores that were abundant in the seagrass meadows, but the golden-lined rabbitfish, *Siganus lineatus,* was ubiquitous and abundant in all Remote Underwater Video (RUV) deployments. Stable isotope and gut-content analyses confirmed that the diet of *S. lineatus* is primarily comprised of seagrass, especially *Thalassia*. *S. lineatus* is a highly valued seasonal food source for the Bardi Jawi people, who call them *barrbal*.

Another potentially significant herbivore is the green turtle, *Chelonia mydas*. Green turtles were seen during RUV deployments, but not in great abundance. However, boat-based transects during the rising tide found that they were abundant over the seagrass beds of Jalan and Iwany. Stable isotope and gut-content analyses showed that Green Turtles consumed a range of plant foods, but brown algae and the seagrass *Thalassia* were particularly prominent in their diet. There was some, albeit equivocal, evidence that different individuals might have preference for brown algae or seagrass. Satellite tags showed that individual turtles frequently tended to spend their time in places with abundant seagrass.

2 Implications for management

2.1 Fish recruitment

The key considerations and recommendations from this research for natural resource managers and other potential end-users are:

- Conservation policy and planning should recognize that all marine habitats provide a unique contribution to the overall pool and diversity of the Kimberley's fish fauna by providing fish nurseries and therefore warrant some level of protection.
- Sampling in the Kimberley usually requires additional resources, development, refinement and testing of established and innovative techniques to ensure they work in this remote and challenging environment.
- Juvenile fish diversity in the Cygnet bay and Sunday Island group was surprisingly low considering its proximity to the equator and global centre of fish diversity. More research into how challenging macro-tidal systems affect patterns of juvenile fish recruitment is needed.
- This project provides quantitative scientific evidence that traditional management practices are well founded.

- Future monitoring should concentrate sampling in the wet season (March / April) within mangrove, seagrass and coral reef habitats in order to get the strongest and most comprehensive assessment of juvenile fish recruitment.
- Fish recruitment underlies replenishment of populations; however rates of recruitment vary spatially and temporally and comprehensive monitoring of fish recruitment will be expensive, especially in remote locations like the Kimberley. Monitoring of adult fish numbers, which are less variable, may be an easier way to assess the health of the Kimberly's fish fauna and should therefore take priority over recruitment surveys. When monitoring of fish recruitment is possible it should focus on species under the greatest anthropogenic pressure and those that perform key ecological roles.

2.2 Coral recruitment

The key considerations and recommendations from this research for natural resource managers and other potential end-users are:

- Corals are important habitat-forming organisms in the inshore Kimberley, and they rely on movement of larvae to maintain populations and recover from disturbance. Understanding coral reproduction & recruitment promotes a greater understanding of which populations are potentially vulnerable to disturbance.
- A protocol was developed for quantifying coral recruitment using frames deployed and retrieved from a small vessel, without requiring SCUBA diving or long periods in the water, to accommodate the hazardous conditions in the Kimberley.
- The recruitment frames were retrieved, tiles changed, and then re-deployed, by the Bardi Jawi Rangers during most months throughout the year. The tiles were also processed and preserved for later analysis by the Bardi Jawi Rangers.
- Coral spawning was detected in March-April and, to a lesser extent, October-November, at similar times to other reefs in the region. However, the occurrence of a coral bleaching event during the primary time of spawning meant that results could not be considered as typical (recruit numbers may be higher in the absence of coral bleaching).
- A large proportion of the coral recruits were from brooding species, with recruitment occurring in many months of the year. For some family groups containing brooding corals, higher recruit numbers were recorded during the summer months. In other family groups, recruitment occurred in many months throughout the year.
- Differences among locations (10s of km apart) were considerable, with variation in both the number and families of coral recruits. For some coral groups, differences at smaller spatial scales (100s of metres) were also important.
- Additional sampling in future years would provide information on recruitment in a more typical year for comparison. Sampling should encompass several locations and a nested sampling design to further examine spatial variability in recruitment patterns.
- To provide useful information on larval supply from coral recruitment studies, it is critical to know the reproductive mode of recruiting corals, the times of spawning and planulation, and to standardise the periods over which tiles are weathered prior to recruitment and are retrieved afterwards.

2.3 Herbivory

The key considerations and recommendations from this research for natural resource managers and other potential end-users are:

- The research reinforces the importance of marine plants, especially seagrasses, to the diet of Kimberley marine fauna. We have shown that seagrass consumption is high, and is a major component of the diet of several herbivores. The herbivores are important to the Bardi Jawi (both golden-lined rabbitfish (*S. lineatus*) and green turtles as a seasonal food cultural resource) and likely to other saltwater communities of the Kimberley. Management plans for areas that contain seagrass beds or stands of macroalgae should consider these as Key Performance Indicators;
- Given the important ecological role that seagrass consumers play, monitoring abundances of these taxa is desirable. The imperative for monitoring the abundance of Green Turtles is also supported by their status as a protected species and their high value in monitoring and management of the indigenous Healthy Country Plans for the region;
- Some work is still needed to develop methods for monitoring that can be adopted and applied uniformly by indigenous ranger groups for Healthy Country Plan monitoring, preferably one consistent with current state-of-the-art methods used for monitoring of marine protected areas;
- The importance of seagrasses to large vertebrate herbivores can be easily monitored through simple tethering experiments which can be useful to assess the resilience of the seagrass and its grazers; and
- Studies of the movement of green turtles might help identify seagrass beds and other important primary producer habitats.

3 Key residual knowledge gaps

3.1 Fish recruitment

This project is the first to provide baseline information on fish recruitment processes in the Kimberley using surveys of post-recruitment juvenile fish. However, a number of knowledge gaps remain including:

- **Spatial area:** While the project provides a solid baseline of knowledge on fish recruitment processes in the Cygnet Bay and Sunday Island group at the entrance to King Sound, results should not be extrapolated outside this area. An expansion of surveys using the same technique would be needed to properly characterise the Kimberley.
- **Duration of study:** Recruitment of all marine organisms is inherently variable from year to year and what variables drive these patterns under what conditions remains a hotly debated topic. Further, 2015/16 recorded unprecedented high-water temperatures in NW Australia suggesting that reproduction and recruitment activities may have been severely affected. Surveys over decadal time periods would be needed, coupled with oceanographic studies over local and regional scales before a detailed understanding of this process could be made possible.
- **Habitat heterogeneity:** The nature of the Kimberley benthos in the survey area is a mixture of inter-blended habitat types. While the importance of discrete nursery habitats is beginning to be understood, the significance of habitat mosaics to fish recruitment processes and their value as nursery grounds remains largely unknown.
- **Macro tidal systems:** Fish diversity was surprisingly and unexpectedly low considering the range of nursery habitats available and the survey area's proximity to the equator and global centre of fish biodiversity. Further, of the 134 species recorded in our surveys, less than half were recorded in their juvenile forms suggesting that macro tidal conditions may well provide unassailable challenges to many fish species, particularly small juveniles. Further targeted research into the ecological strategies used by fishes to overcome these barriers is needed to better understand fish recruitment processes in challenging conditions.

3.2 Coral recruitment

This project provides baseline information on coral recruitment processes in the Kimberley using surveys of coral recruits settling on artificial substrate (settlement plates). A number of knowledge gaps remain, including:

- **Temporal variability:** As this study took place in an atypical year (when an unprecedented coral bleaching event occurred), sampling in additional years would be necessary to gain a more detailed understanding of seasonal variation in recruitment processes.
- **Spatial variability:** The variation among locations in this study highlighted the potential diversity present within Kimberley coral reefs. Due to these high levels of spatial variability, the findings documented here may not be directly applicable to reefs in the wider Kimberley region.
- **Post-recruitment survival:** Survival from settlement into the juvenile and adult life stages was not part of the scope of this project, but is a key element of the maintenance of coral communities. Long-term monitoring programs can provide further insight into coral growth and survival, which shape the coral reef community.
- **Larval movements:** Understanding the sources of larvae and their patterns of movement before settlement remains relatively unknown. Understanding patterns of larval movement could help predict areas of high and low recruitment.
- **Reproductive modes:** The mode of reproduction (spawner, brooder) remains unknown for some common Kimberley corals. In particular, some species of massive *Porites* were previously assumed to be spawning corals, although brooders have since been reported. It is not known whether the extended period of *Porites* recruitment was due to protracted spawning and/or recruitment of brooded larvae.

3.3 Herbivory

This project has significantly increased our understanding of the importance of herbivory as a process in the Kimberley, and the relative importance of different primary producers as food for herbivores. It has also highlighted a number of knowledge gaps. Key among those gaps are:

- **Abundance of herbivores:** we have limited information about the true abundance of key herbivores such as the golden-lined rabbitfish and green turtles. Green turtles are listed threatened species that are also important food and cultural resources for indigenous communities in the Kimberley, and there is a need to understand their patterns of abundance and distribution;
- **Movement:** we were able to conduct relatively limited studies of the movement of green turtles, but these showed that individuals range widely over relatively short time periods, in contrast to other parts of Australia. Many individuals moved between regions covered by different Healthy Country Plans, implying a hitherto under-appreciated level of connectivity. This remains poorly understood;
- **Wider understanding:** We were only able to focus on herbivory in one type of habitat (seagrass meadows), and the diet of two key herbivores (golden-lined rabbitfish and green turtle). The importance of herbivory in other habitats (e.g. reef), and by other key herbivores (e.g. surgeonfish, dugongs) remains unstudied in the Kimberley; and
- **Deeper meadows:** as highlighted in the WAMSI KMRP project 2.2.4 (Benthic primary productivity), our understanding of ecological processes in deep meadows is poor. These meadows are potentially more important for dugong and there is a need to understand niche resource partitioning among Kimberley herbivores.

4 Management questions

This project directly addresses the following questions outlined in the Kimberley Marine Research Program Science Plan in addition to questions raised by the managers and planners.

Key Question	Informed Response
1. What are current baseline levels of fish and coral recruitment and how do these compare to other areas of Australia?	An informed response needs to be prefaced with the fact that sampling was partially conducted during unprecedented high-water temperatures which have been found to have both positive and negative effects on the strength of coral and fish recruitment. Thus, while data was collected on both fish and coral recruitment, 2015/16 was an anomaly period making it difficult to categorise this data as baseline without further evidence of interannual variation. **Fish Recruitment:** For fish, baselines are not comparable to other areas of Australia because this program was the first to use Remote Underwater Video as a method to quantify juvenile reef fishes. The method uses MaxN, which is the maximum number of individuals from each species seen within a single frame, making comparisons with direct counts (the method commonly used elsewhere in Australia) impossible. **Coral Recruitment:** For corals, recruitment is not directly comparable with other areas of Australia due to the occurrence of coral bleaching during the primary period of predicted mass spawning (March-April). However, there were recruits from spawning corals (*Acropora)* detected primarily during this time, and again in low numbers in Oct-Nov, which suggests that the timing of mass spawning, under normal conditions, would be similar to that documented at other Western Australian reefs (for spawning corals: major spawning event in March-April, smaller spawning event in October-November).
2. What are current baseline levels of herbivory, and how do these compare to other areas of Australia?	Current levels of herbivory on seagrass appear to be among the highest in the world. Estimates of consumption of *Thalassia* were higher than those of *Enhalus*, and were comparable to (albeit higher than) estimates from tropical seagrasses in Indonesia. The estimates are, on average, higher than those recorded elsewhere in Australia.
3. What's the spatial and methodological framework for managers to do this work in the future (how do we collect data on these processes over the long term)?	This project was concentrated in the Cygnet Bay and Sunday Island group of the west Kimberley only. Rollout to the rest of the Kimberley would best be approached utilizing local indigenous knowledge in areas of interest, areas of perceived importance or those under imminent threat. For regional patterns of recruitment of fishes and corals, studies over large geographic areas would need to be conducted in synchrony by multiple teams at multiple geographic locations. It is unlikely that this is feasible and we recommend local-scale sampling using the methods developed here. The macro-tidal conditions found in the Kimberley provided an opportunity to develop and refine new methods and techniques which are robust enough to deal with the challenging hydrological conditions of the Kimberley (e.g. tidal currents, turbidity, exposure). This included; **1) Fish Recruitment:** Unbaited remote underwater video frames using stereo cameras to accurately determine size of individuals. This coupled with sampling on neap tides or 1-2 hours either side of spring highs and lows to enhance underwater visibility for camera work. **2) Coral Recruitment:** We designed, developed, tested and constructed frames on which coral recruitment tiles were mounted. This allowed the frames to be deployed and retrieved from the surface, without the need for SCUBA diving, which is logistically difficult in remote areas. The frames were able to withstand strong currents without movement or vibration (which may affect settlement processes). Use of the frames also assisted in re-locating the coral tiles when visibility was poor (common at two of the five locations). **3) Coral Recruitment:** In future, ideal methodologies would combine the methods used during this sampling program, with other complementary surveys (coral long-term monitoring program, reproductive surveys, genetic analyses). This would build on the understanding of larval supply which we gained from this project, by expanding knowledge of the abundance of various coral genera at each location, and gain further understanding of patterns of larval movement, identifying 'sources' and 'sinks' of coral larvae, and post-settlement survival rates of corals. The implementation of a coral long-term monitoring program in particular would improve our understanding of the response of the unique coral reefs in the inshore Kimberley to global threats to coral reefs, such as coral bleaching.

	4) Herbivory: Measurements were done in seagrass meadows of the raised lagoons on Sunday and Tallon Islands, using methods proven to be effective elsewhere. Different species of seagrasses are likely to be present in other habitats (e.g. deeper water), and in more turbid regions of the Kimberley. In addition, the study of diet focused on species of particular importance in the study area. Green turtles are likely to be just as important in other parts of the Kimberley, but their diet might vary depending on the resources available. Other species of fish will be more or less important in other habitats (e.g. parrotfish and surgeonfish are likely to be more important on reef habitats). While information on diets of other species and places will be valuable (and can be collected using the methods outlined here), greater emphasis in the short-term should probably be placed on developing robust monitoring for seagrasses. Knowledge of green turtle abundance remains a critical knowledge gap. Together these developments and refinements provide a blueprint of how to survey and monitor recruitment and herbivory in the Kimberley marine environment, the equipment needed and steps to take for their accurate assessment and quantification.
4. What are the important months for spawning and recruitment?	**Fish Recruitment:** Seasonal sampling of fish recruits in mangrove, seagrass, algal, coral reef and inter-tidal pool habitats identified the wet season (March/April) was providing the strongest signal of fish recruitment for both abundance and diversity although there were exceptions (see report Figure 8). In addition, bi-monthly sampling of fish recruits in coral reef habitats identified that seven of the top ten species would be best surveyed between the December and April period. **Coral Recruitment:** Coral recruitment occurred throughout the calendar year, although overall recruit numbers were highest in November 2015, followed by September and October 2016. The coral families Pocilloporidae and Poritidae (the most common recruits) were present in all months of the year. For both of these families, this could be due to a combination of brooding species releasing larvae monthly, and spawning corals releasing gametes in many months (both families contain both spawning and brooding species). We saw a small peak in abundance of *Acropora* recruits in March-April, and again in smaller numbers in October at some locations, although numbers of these recruits were likely reduced by the stress associated with coral bleaching observed during March-May at the study locations (coral bleaching is documented to reduce reproductive output both during and after bleaching events).
5. What habitats support which species and what do we need to do to support the important species of the Kimberley?	Fish nursery habitats differed in their fish recruitment support roles with each of the five habitats supporting a different assemblage of species. Species assemblages were most different in mangrove and seagrass habitats with coral reefs, algal and intertidal pools having a stronger potential to act as surrogates for each other under a more restricted program. Mangroves strongly and almost exclusively provided a nursery habitat for juvenile Mangrove jack (*Lutjanus argentimaculatus* - Maarran) and Moses perch (*Lutjanus russelli*), seagrass beds the important herbivorous Golden-lined rabbitfish (*Siganus lineatus* – Barrbal) with the remaining three habitats supporting a more diverse and mixed assemblage. Safeguarding the health and diversity of all five Kimberley habitat types is the best way to ensure ongoing replenishment of fish stocks at the local level.
NEW QUESTIONS POSED BY MANAGERS ON 28TH FEBRUARY 2017	
What works and what doesn't when it comes to quantifying these ecological processes?	**WORKS** **1) Fish Recruitment:** Working in with relevant indigenous marine rangers to understand and share local geographical, oceanographic and ecological knowledge is critical to underpin this research and/or monitoring. **2) Fish Recruitment:** Deploying any underwater video technique either during neap tides or 1-2 hours either side of spring high and low tides is essential to minimise turbulence and ensure best visibility. **3) Fish Recruitment:** Underwater camera rigs recording fish recruits do not need to be baited as this will likely attract predators. Accessing standard bait items such as pilchards can also be logistically difficult in remote areas of the Kimberley. Juvenile fishes tend to be sedentary so unbaited rigs provide good estimates of abundance and diversity within camera field of view. **4) Coral Recruitment:** The use of frames (allowing coral recruitment tiles to be raised and lowered from the sea bed without divers) was very successful and provided monthly data indicating when coral recruitment was taking place. **5) Coral Recruitment:** The local management of monthly sampling by the Bardi Jawi Rangers was vital to the success of the coral recruitment project. Retrieving the frames was often delayed due to poor weather

	conditions affecting both sea state and visibility. Without the input of local groups, the project would have consumed vastly greater resources (both cost and time) with much fewer results. **6) Coral Recruitment:** Maximising the available working time by utilizing the most suitable tidal windows was critical. Again, without the extensive local knowledge brought by the involvement of the Bardi Jawi Rangers, this would have been difficult to impossible. **7) Herbivory:** Simple tethering methods, in conjunction with studies of seagrass growth, were effective. Caging experiments would provide additional value to support the inferences. **DOESN'T WORK** **1) Fish Recruitment:** Divers underwater for census work; still camera, box trawls and patch reef aggregation devices for quantifying fish recruitment. **2) Fish Recruitment:** Trying to stratify sampling regime by specific habitat because the benthic community tends to be a diverse mosaic of inter-mixed habitats. Exceptions are seagrass and mangrove habitats which tend to be more homogenous and able to be stratified. **3) Coral Recruitment:** The timing of deployment and retrieval of tiles in relation to the predicted times of spawning is critical (e.g. tile changeovers on a particular day). If tiles are not deployed at the appropriate times the approach does not work- data are not comparable among months, years and/or other studies. **4) Coral Recruitment:** Incorporating additional measures quantifying the coral communities at each location, and in the broader region, in more detail would assist in interpreting coral recruitment data and understanding the relationships between larval supply, recruitment and the survival of corals into adulthood. **5) Coral Recruitment:** As recruit numbers were relatively low, we suggest that future surveys consider incorporating additional replication at the tile level, in order to capture sufficient numbers of recruits for analysis (although to some extent, the low numbers were likely a reflection of stress associated with increased water temperatures and coral bleaching). **6) Herbivory:** Placement of cameras near areas of mangrove yielded poor video that could not be analysed. In addition, attempts to trap herbivorous fish largely did not work.
Where to from here, relevant questions?	**1)** Did unprecedentedly high water temperatures in 2015/16 impact coral and fish recruitment numbers? **2)** Are the patterns observed in the Cygnet Bay and Sunday Island group indicative of those of the rest of the Kimberley region **3)** How can the measures of fish recruitment with RUVs be modified so they can be compared to data from other locations? **4)** Is the low diversity found in the juvenile fish fauna a consequence of the challenging hydrological conditions of Cygnet Bay and Sunday Island group and the challenges it poses to small larval fishes or representative of the Kimberley region in general? **5)** How stable are fish nursery grounds given they are living habitats which also respond to global pressures personified by climate change in the marine environment? **6)** Are the low numbers of coral recruits at some locations, and in some coral groups, persistent, or variable among years? **7)** Can a combined approach utilizing additional techniques (reproductive sampling, genetic analysis, coral monitoring program) provide more detailed, species- or genera-level information regarding which corals reproduce at which time, and on the movement of larvae throughout the study area? **8)** Knowledge of the abundance of green turtles is a critical knowledge gap. The ubiquity of green turtles as KPIs throughout the Kimberley, in marine parks plans and Healthy Country plans, all highlight the need for this knowledge.
Restrictions in what the information will provide to management.	Recruitment of corals and fish is inherently stochastic in nature requiring multi-year studies to detect significant changes or detrimental effects. Once detected, determination of whether it is a larval supply (i.e. regional) or juvenile survivorship (i.e. local-scale) issue then needs addressing. This is a decade-long exercise. All results herein must also be interpreted with some caution given sampling was conducted during a period where protracted water

	temperatures were the highest experienced (as evidenced by the local indigenous communities comments that they had no history of corals bleaching). **Fish Recruitment:** What this project has clearly identified for fish recruitment is which habitats provide fish nursery areas to which species; the range and importance of habitat type to this process, ways in which to conduct accurate surveys and the best timing to conduct these. **Coral Recruitment:** What this project has clearly identified for coral recruitment, is the large variation among locations and months for most groups of coral recruits. The information is also limited to key coral groups, so more detailed information regarding individual coral species and/or genera requires the addition of complementary approaches. **Herbivory:** What this project has clearly identified for herbivory is that consumption of seagrass is very high (especially of *Thalassia*), and that seagrass in turn comprises a very important part of the diet of rabbit fish and green turtles, which are culturally important for the Bardi Jawi people. The activities of the herbivores likely shape the seagrass ecosystem.

5 Report Structure

The full report for WAMSI project 1.1.2 is structured as an executive summary, three individual sub-project reports that focus on different marine organisms.

The following sub-reports are included as separate documents:

1.1.2a Key Ecological Processes in Kimberley Benthic Communities: Fish Recruitment

1.1.2b Key Ecological Processes in Kimberley Benthic Processes: Coral Recruitment

1.1.2c Key Ecological Processes in Kimberley Benthic Processes: Herbivory

6 Key communication activities

Students supported
Camilla Piggott commenced a PhD in November 2014 as part of the fish recruitment component of the project. Camilla is based at AIMS / OI with her PhD candidature administered through the School of Plant Biology at the University of Western Australia. The nominal title of her PhD is "Fish replenishment processes in the Kimberley region of NW Australia". She is expected to submit her thesis in August 2018.
Lisa DeWever (M. Sc., European Institute for Marine Studies, France), Lucie Chovrelat (M. Sc., European Institute for Marine Studies, France), Emy Guilbault (M. Sc., Montpellier SupaGro, France) all satisfied part of the requirements of their degrees through specific projects that added value to the work presented here, including the rabbitfish stomach contents, and seagrass tethering.
Journal publications
Proceedings/Technical Reports
Kendrick GA, Fraser MW, Cayabyab N, Vanderklift M (submitted) Seagrasses of the Kimberley. Natural World of the Kimberley Proceedings. Kimberley Society Seminar 16th October 2016, The University of Western Australia, Crawley
Submitted manuscripts
As above
Presentations
Depczynski M (2017) Parks and Wildlife Lunch n Learn Series (28th February 2017) Presentation on Key Ecological Processes in Kimberley Benthic Communities – Fish recruitment
Depczynski M (2016) Presentation to Kimberley Marine Research Station. April 2017.
Gilmour J (2017) Parks and Wildlife Lunch n Learn Series (28th February 2017) Presentation on Key Ecological Processes in Kimberley Benthic Communities – Coral recruitment
Vanderklift M (2015) Presentation to One Arm Point school
Vanderklift M (2016) The ecology of green turtles in Bardi Jawi sea country. 3rd Australian Sea Turtle Symposium, Darwin, 22-24th August 2016.
Vanderklift M (2016) Presentation to Kimberley Marine Research Station. April 2014.
Vanderklift (2017) Parks and Wildlife Lunch n Learn Series (28th February 2017) Presentation on Key Ecological Processes in Kimberley Benthic Communities - Herbivory
Regular presentations of project results to Bardi Jawi rangers during each survey by all sub-project

leaders.

Other communications achievements

Class and field activities with One Arm Point Remote Community School.

Key methods for uptake (ie advisory committee, working group, website compendium of best practice.)

KISSP Presentation mid 2016.

KSN 1.1.2 Summary Document (Feb 2017) – Key Ecological Processes in Kimberley Benthic Communities https://indd.adobe.com/view/64e01346-0848-4800-9a1c-1424014b6e44

KSN 1.1.2 KMRP Meeting with Node Leader and KMRP Advisory Group to discuss management needs and application (28 February 2017)

Other

KMRS Newsletter (October 2014) *"No diet restriction for the rabbitfish"*

Science Network WA (May 2015) *"What's eating you? Solving the seagrass mystery."* http://www.sciencewa.net.au/topics/aboriginal-science-a-knowledge/item/3536-what-s-eating-you-solving-the-seagrass-mystery

WAMSI Article (August 2015) "*Schools out on tropical fish nurseries in the Kimberley"* http://www.wamsi.org.au/news/school%E2%80%99s-out-tropical-fish-nurseries-kimberley

KMRS Newsletter (October 2015) *"Juvenile fish recruitment dynamics"& "Coral communities"*

KMRS Newsletter (February/March 2016) *"Juvenile fish recruitment dynamics"*

KMRS Newsletter (April/May 2016) *"Tagging turtles"*

KMRS Newsletter (April/May 2016) *"Juvenile fish recruitment"*

KMRS Newsletter (April/May 2016) *"Tagging turtles"*

KMRS Newsletter (June/July 2016) *"Milly's return – Juvenile fish recruitment"*

WAMSI Article (November 2016) *"Field trip finds turtle and fish food abundant in Bardi Jawi country*" http://www.wamsi.org.au/news/field-trip-finds-turtle-and-fish-food-abundant-bardi-jawi-country

CSIRO ECOS Blog Article (December 2016) A field trip to Bardi Jawi country: turtles and fish and seaweed, oh my! https://blog.csiro.au/a-field-trip-bardi-jawi-country-turtles-fish-food-and-fun/

DPaW Kimberley Tide Article (December 2016) Field trip to Bardi Jawi country

KMRP WAMSI 1.1.2 Summary: Key ecological processes in the Kimberley: recruitment and herbivory