Rapid Assessment of Australian MPAs using Satellite Remote Sensing

Report to Environment Australia

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1. Summary

Protection and management of species occupying the surface waters of Marine Protected Areas (MPAs) is difficult because of the temporal and spatial shifts in surface environments. Understanding the physical patterns in these environments through rapid assessment of available data is important in increasing the success of management efforts. This report explores the potential for using satellite data to rapidly assess the historical environmental state at twelve commonwealth MPAs. Sea surface temperature (SST) and sea surface color (SSC) data were extracted from satellite images for the periods 1991-99 and 1997-99 respectively. A description of the range and mean conditions was provided for the nine years of SST data and the three years of SSC data. Climatologies generated from these data described the seasonal signal for the surface environment. Univariate habitat definitions for the surface waters have been developed using SST and SSC measures, and the temporal and spatial description of these habitats is presented. The adequateness and representativeness of the MPAs can be evaluated by estimating the fraction of the similar surrounding habitat that is contained within each MPA. Collectively these data provide a baseline for managing and monitoring the MPAs and indicate additional regions around Australia without protected surface habitats.

2. Introduction

Rapid assessment is crucial in quickly establishing if regions meet criteria allowing for protection of species or habitats. The techniques for rapid assessment should be specific to the habitat in question with different vital signs expected in different systems. Vital signs are those subsets of ecosystem state-variables that capture the essential dynamics of the system utilizing as few variables as possible. The identification and validation of region-specific vital signs is an important step in evaluating existing Marine Protected Areas (MPAs) and establishing protocols for creation of new ones. Two vital signs in marine regions are temperature and productivity. An understanding of these vital signs is likely to streamline monitoring and management efforts to optimize the use of limited funds and personnel.

Australia's MPAs are spatially and temporally fixed. While the seafloor and associated taxa can be considered as fixed, the surface waters are not. Thus, the current MPAs offer maximum local protection for the resident or sedentary seafloor species, but only temporary protection for the mobile species occupying the surface waters. Attention to the physical characteristics of the surface waters will allow an understanding of the patterns that might influence the presence or absence of surface-living species, and hence the effectiveness of the MPA in protecting such species. Surface characteristics, or vital signs, such as sea surface temperature (SST) and sea surface color (SSC, a proxy for chlorophyll, and hence phytoplankton), are currently measured by satellite. SSC is high in high productivity areas, and is often used as a proxy for this characteristic. Satellite coverage allows rapid assessment of the surface expressions of SST and SSC over a wide area. Surface expressions of SST or SSC characteristics may be critical vital signs that identify regions or hotspots that are important for pelagic species such as tunas, sharks, billfish, sea birds and marine mammals. A historical baseline of surface characteristics derived from satellite data can be used to evaluate perturbations in the surface waters. The impact of climatic shifts and variation and anthropogenic influences can then be assessed, and action taken where necessary or possible.

Assessment can be rapid using historical or contemporary data. This report provides baseline historical satellite SST and SSC information for monitoring the pelagic MPA environments. This remotely sensed information is used to describe the surface climatology at each of twelve established Australian Commonwealth MPAs (**Figure 1**). The variation in SSC and SST at each site is also described, together with an estimate of the size of the habitat with similar characteristics and its variation through time. The fraction of similar habitat covered by each MPA allows the completeness and adequateness of the MPA to be evaluated. Finally, identification of additional regions for protection and management is possible with the information presented here.

3. Methods

Each Commonwealth MPA was first defined by its boundary coordinates, as supplied from the Environment Australia ERIN database (**Figure 2**), which allowed the size of each MPA to be calculated. Data for each available satellite image were then extracted for each MPA, using customized software routines. For this study, SST data were available every 10 days from 1991 to 1999 at a scale of $5km^2$. The SST data has been optimally interpolated to provide complete spatial coverage between 108°E to 160°E and 45°S to 5°S (Walker and Wilken, 1998). The SeaWiFS ocean color was available every eight days from September 1997 to October 1999 at a scale of $9km^2$; algorithms to optimally interpolate color data (SSC) are still under development and so non-interpolated data was used in the area from 90.9°E to 179.1°E and 65.1°S to 5°S. Although SSC data is commonly referred to as chlorophyll, in coastal waters the relationship between color and chlorophyll (CHL) is less straight forward. In this report, the term SSC will be used, rather than CHL although the units are CHL concentration, $mg.m^{-3}$). SSC data is also affected more by cloud cover than SST data, and so spatial coverage is less complete. Example SST and SSC images are shown in **Figure 3**.

Time Series and Climatologies

The maximum, minimum, mean, median and standard deviation for SST and SSC were found for each date within each MPA. The number of pixels (each representing $5km^2$ (SST) or $9km^2$ (SSC)) that were considered in producing these statistics was also recorded. The monthly SST and SSC climatologies were calculated for each MPA by averaging the median temperatures found in each month. For example, the January SST climatology value was found by averaging the median SST's for any date in January between 1991 and 1999. Bounds to indicate extreme values were set using ±2SD, which if data are normally distributed, should contain 95% of the data. Thus, values that fall outside the bounds are the 5% of extreme cases based on a normal distribution.

Habitat definitions

Habitats can be defined by the characteristics of the physical measures of the area in question. For example, an area where the SST is between 19°C and 20°C defines a particular thermal habitat. Similar univariate habitat descriptions can be created for SSC. However, the twelve Commonwealth MPAs are spatially fixed while the surface water characteristics vary temporally. Thus, the habitat that the MPAs contain will also vary temporally. The habitat might not be restricted to the MPA and so the size and geographic location of the whole habitat is important to evaluate the comprehensiveness, representativeness and adequateness of each MPA with respect to that habitat.

Multivariate habitat descriptions might provide a better description of the environment that an animal requires or experiences. For example, perfect water temperature might be inadequate if there is no food available. Future investigations into multivariate habitat descriptions may lead to further insight about marine environments and the species that use them.

In this report univariate habitats were defined for each MPA for each day of satellite data, according to the following criteria. The environmental value at the center of each MPA was used as the initial habitat value. Transects of width 0.5 (SST) and 1° (SSC) were created radially away from the center in 8 directions (N, NW, W, SW, S, SE, E, NE) (**Figure 4)**. The median value of the variable was found in equally spaced distance bins moving away from the start of each transect at the center of the MPA. The boundaries of the habitat along each transect were defined as the position where the median value declined (increased) below (above) some percentage change of the center value (**Figure 5)**. Percentage changes were used so that the same definition could be applied to all the MPAs. If absolute changes (such as ±X°) were used, then the percentage change required varied with the MPA location. The edge of the habitat was defined as the center_value±25% change for SSC and the center_value±2.5% change for SST. The size of the percentage change is subjective, and was selected based upon observation of the change in each property with distance from the MPA center. The polygon enclosed by the boundaries of the habitat in the eight directions defined the extent of the habitat on that date. The area of the habitat was found for each date for each MPA. Maximum and median distances that the habitats extended away from the MPA center were found by month and year and for month regardless of year (climatology).

The frequency of occurrence for each habitat type (e.g. 19°C habitat) centered at each MPA was calculated, while cumulative frequency analysis indicated the percentage of months that each MPA contained a particular habitat. The relationships between the habitat type and the habitat area was explored for both SST and SSC for all the MPAs.

Monthly and maximum MPA habitat areas summarized on a map of Australia indicate the extent of pelagic habitats that are covered by the existing MPAs. Gaps in the distribution of protected habitats around Australia should help focus efforts for new MPAs.

4. Results and Discussion

Values by Date and Climatologies

A total of 99 SSC (10/9/1997-28/10/1999) and 290 SST (18/3/1991-14/2/1999) images were used to describe the SST and SSC environment at each of twelve Commonwealth MPAs. The SST and SSC statistics by MPA and date are provided as datafiles with this report (**Appendix 1).** The number of pixels contained by the boundary of each MPA was related to the size of the MPA (**Figure 6)**.

Between six and 300 pixels were considered for SST (**Figure 7)** and between one and 110 pixels for SSC (**Figure 8)** statistics in each MPA. The large size of the rectangular area around the Great Australia Bight and Coringa Herald MPA led to computational problems, and so a random subset of the total number of pixels was selected to derive the statistics. The typical distribution and number of pixels for a single SST extraction is shown for each MPA in **Figure 2**. The number of pixels for each MPA SSC extraction was fewer than for SST due to the coarser scale of the data and more variable due cloud contamination in those images.

The monthly SST climatology shows strong seasonal patterns at each MPA (**Figure 9)**, while the SSC climatology is less seasonal (**Figure 10)**. The median SST (**Figure 11**) and SSC (**Figure 12)** by month shows the variation in each month that is hidden in the climatology, while the maximum and minimum values for SST (**Figure 13**) and SSC (**Figure 14**) show the range of values at any date. These data all show essentially the same signals, but could be used for different purposes. For example, the maximum and minimum data would indicate the absolute range of values in the MPA, while the medians show the average signal by date. For larger MPAs the range may be the most conservative test for a particular value of SST or SSC occurring within the MPA, which is important in deciding if appropriate conditions for a species existed at that time.

The SST time series for each MPA, together with the climatology, are shown in **Figures 15-25**, while **Figures 26-37** show the SSC time series. In general, the annual cycles appear to be very similar with no really anomalous years noted for the time period examined (i.e. no values > ±2SD from the climatology). Time series for the maximum and minimum values could have also been shown, and can be created from the datafiles accompanying this report. The limited temporal coverage of the SSC data makes it less valuable than the SST data at this time, as the seasonal signal has not been well described. Alternatively, there may no be an obvious seasonal SSC signal at many of the MPAs, which allows the average of SSC values throughout the year to describe the range of conditions that are found at these locations. The relationship between SST and SSC conditions during the months when both data types were available (1997-1999) varied between the MPAs (**Figure 78).** The strongest relationships were for negative correlations between SST and SSC on the east coast of Australia. These baseline SST and SSC results are presented and discussed in greater detail for the twelve Commonwealth MPAs later in the report.

Habitat areas

The geographical extent of the mean habitat areas found for each MPA are shown by month in **Figures 38-48** for SST (**Table 2)** and **Figures 49-60** for SSC (**Table 3)**. These data are provided in accompanying datafiles, as described in **Appendix 2**. Large habitat areas indicate that there were similar conditions over a wide area, while small habitat areas indicate more localized conditions. Lack of SST data for Macquarie Island meant that its habitat area was only defined using SSC.

The size of the habitat areas differed by month, and the change in habitat area is summarized for SST (**Figure 61, Table 2)** and SSC (**Figure 62, Table 3)**. Distinct seasonal cycles in the mean size of the SST habitat can be seen for some MPAs. The SST habitats are largest in the autumn months (February-May) when seven of the 11 MPA habitats are at a maximum mean size and smallest between October-March when ten of the 11 MPA SST habitats are at the minimum mean size (**Table 2)**. The size of the SSC habitats fluctuates dramatically throughout the year for most of the MPAs, but often without a strong seasonal signal. In general, the SSC habitats are largest in the spring months (July-October) when nine of the 12 MPA habitats are at a maximum mean size and smallest between January-June when ten of the MPA SSC habitats are at the minimum mean size (**Table 3)**. The mean SST and SSC habitat sizes for each month are smaller than the maximum sizes ever observed (**Figure 61 and 62)**, suggesting large interannual variation, however, using the mean size is a more conservative measure of the habitat area.

The frequency distributions of the SST (**Figure 63)** and SSC (**Figure 64)** habitat conditions describe the physical conditions likely to be found at each MPA. Each MPA could thus be categorized by the most common habitat condition. For example, Ningaloo could be described as protecting the 25°C pelagic habitat. Although the median conditions for each MPA have already been described, similar summaries can be made for the average conditions for the SST (**Figure 65)** and SSC (**Figure 66)** habitat areas. The same seasonal cycle was found for the SST and SSC habitats as for the MPA time series and climatologies. An alternative method of describing conditions found in the habitat areas is to examine the cumulative frequency of each habitat condition for SST (**Figure 67)** and SSC (**Figure 68)**. These plots show the percentage of each monthly habitat value that was found. Instead of a single value, a MPA habitat might be described as having 50% of the values between 28° and 30°C.

The adequateness of each MPA can be expressed as the percentage or fraction of the total habitat area that is enclosed within the boundaries of the MPA for SST **(Figure 69)** and SSC (**Figure 70)** habitats. Small fractions indicate that the MPA covers only a small portion of the total similar pelagic habitat, while fractions greater than one occur when the habitat area is smaller than the MPA. The fraction of the habitat that each MPA covers indicates that in general the habitats defined by SSC are covered more completely by the MPA **(Table 1)**. That is, more of the particular habitat (defined by the conditions at the center of the MPA) is found within the boundaries of the MPA for SSC than for SST. A species preferring that habitat then has a greater chance of being found within the MPA, and hence be protected.

The representativeness of the MPA system for coverage of pelagic habitats can be evaluated by considering the distribution of the MPA habitats around Australia by month for SST (**Figure 71)** and SSC (**Figure 72).** These figures show that for all months there are gaps in the protected pelagic environments for both definitions. Summaries for all months for SST (**Figure 73)** and SSC (**Figure 74)** habitats indicate gaps in the current coverage and indicate where future efforts could be directed to develop a more complete coverage of the pelagic environment around Australia. This would allow species using a particular surface habitat to have some portion of that habitat protected throughout the year, which is the situation for many benthic or sedentary species in existing MPA regions.

The SST habitat definitions resulted in larger habitat areas than for SSC, regardless of whether the mean (**Figure 75**) or maximum (**Figure 76**) criteria was used to draw monthly boundaries. Temperature is a more conservative property than the biological and patchy SSC and the larger habitat areas reflect the greater homogeneity of this property in the surface waters. Even if the maximum habitat size ever found for the MPAs using both measures is used, SST habitats were generally larger than SSC (**Figure 77)**. Thus, more MPAs will be required to cover all the SSC habitats around Australia than for SST habitats. The relationships between the size of the SST habitat and the value of the SST habitat were both positive and negative but weak in general (**Figure 79**). Some prediction might be possible at the MPAs where stronger relationships were found. Similar relationships between SSC habitat size and habitat value were also weak (**Figure 80)**. Unfortunately this suggests that little prediction about the habitat size is possible from the habitat values for SSC.

The definition used to describe the boundaries of the habitat influence the size of the habitat. The size of the percentage change was selected after considering the output using a range of values. If the percentage change was too large, edges were not detected; if the percentage change was too small, then "noise" in the signal led to very close and unrealistic boundaries. The percentage change selected matched well with obvious changes in the signal that indicate a change in the water properties (**Figure 5)**.

Patterns at individual MPAs

The basic SST, SSC, and habitat area patterns at each MPA are now described in greater detail.

- Ashmore Reef

    This is one of the three warmest MPAs along with Cartier Island and Mermaid Reef. Higher SST was found in the summer months (December-February), with a range of 28-34°C. During the cooler period (July-September), surface temperatures were 25-28°C (**Figure 13)**. The time series and climatology (**Figure 15)** indicate the 1998 was the warmest year, and 1991 the coolest.

    SSC values at Ashmore Reef were low, although higher than the MPAs at similar latitudes on the east coast (**Figure 64).** The SSC values were highest during the cool period, and lowest during the summer months. There was little inter-annual variation in SSC (**Figure 26)**. SST was negatively correlated with SSC (r=-0.31) (**Figure 78).**

The SST habitat was much larger than the size of the MPA for all months and extended in all directions from the MPA (**Figure 38)**. The mean size of the SST habitat area centered on Ashmore Reef was second largest overall (**Table 2),** being greatest during the winter months (June-August) (**Figure 61)**, when cool SST was found (**Figure 65**). Overall, the MPA covered 0.33% of the mean SST habitat area (**Table 1)**.

In general the SSC habitat extended further to the northeast of the MPA and was larger than the MPA (**Figure 49).** The overall mean SSC habitat size for all months was the smallest of all the MPAs (**Table 3).** The mean size of the SSC habitat was greatest slightly later in the year (**Figure 62)**, after the highest SSC values occurred (**Figure 66**). When the size of the habitat area is large, the fraction covered by the MPA will be small (compare **Figure 61** with **Figure 69**). Overall, the MPA covered 13.10% of the mean SSC habitat area (**Table 1)**.

The mean and maximum SST habitats were larger than the mean and maximum SSC habitat in all months for Ashmore Reef (**Figure 75, 76)**.

- Cartier Island.

This is one of the three warmest MPAs along with Ashmore Reef and Mermaid Reef. Higher SST was found in the summer months (December-February), with a range of 28-32°C. During the cooler period (July-

September), surface temperatures were 25-28°C (**Figure 13)**. The time series and climatology (**Figure 16)** indicate the 1998 was the warmest year and 1991 the coolest.

SSC values at Cartier Island were low, although higher than the MPAs at similar latitudes on the east coast (**Figure 64).** The SSC values were highest during the cool period and lowest during the warm summer months. There was little inter-annual variation in SSC (**Figure 27)**. SST was negatively correlated with SSC (r=-0.34) (**Figure 78).**

Cartier Island had the largest average SST habitat area of all the MPAs (**Table 2).** The SST habitat was much larger than the size of the MPA for all months and extended in all directions from the MPA (**Figure 39)**. The mean size of the SST habitat area centered on Cartier Island was greatest during the winter months (June-August) (**Figure 61)**, when cool SST was found (**Figure 65**). Overall, the MPA covered 0.07% of the mean SST habitat area (**Table 1)**.

In general the SSC habitat extended in all directions from the center of the MPA and was larger than the MPA (**Figure 50).** The mean size of the SSC habitat was small compared to the other MPAs (**Table 2).** The area was largest later in the year (August-November) (**Figure 62)**, than for the maximum SST habitat and after the highest SSC values occurred (**Figure 66**). Overall, the MPA covered 2.06% of the mean SSC habitat area (**Table 1)**.

The mean and maximum SST habitats were substantially larger than the mean and maximum SSC habitat in all months for Cartier Island (**Figure 75, 76)**.

- Mermaid Reef.

This is one of the three warmest MPAs, along with the more northern Ashmore Reef and Cartier Island. Higher SST was found in the summer months (December-February), with a range of 28-32°C. During the cooler period (July-September), surface temperatures were 25-28°C (**Figure 13)**. The time series and climatology (**Figure 17)** indicate the 1998 was the warmest year, and 1991 the coolest.

SSC values at Mermaid Reef were low, although higher than the MPAs at similar latitudes on the east coast (**Figure 64).** The SSC values were highest during the cool period, and lowest during the summer months. There was little inter-annual variation in SSC (**Figure 28)**. SST was negatively correlated with SSC (r=-0.23) (**Figure 78).**

The SST habitat was much larger than the size of the MPA for all months and extended in all directions from the MPA (**Figure 40)**. The mean size of the SST habitat area centered on Mermaid Island was greatest during March-May (**Figure 61)**, when SST was intermediate (**Figure 65**). Like the two more northern MPAs, the overall habitat was large compared to the rest of the MPAs (**Table 2).** Overall, the MPA covered 0.29% of the mean SST habitat area (**Table 1)**.

In general the SSC habitat extended in a north-south direction from the center of the MPA (**Figure 51).** The mean size of the SSC habitat was greatest in May (**Figure 62**) before the highest SSC values occurred (June-August) (**Figure 66**). The overall habitat area was small compared to the other MPAs (**Table 3).** Overall, the MPA covered 7.47% of the mean SSC habitat area (**Table 1)**.

The mean and maximum SST habitats were substantially larger than the mean and maximum SSC habitat in all months for Mermaid Reef (**Figure 75, 76)**.

- Ningaloo.

Highest SST was found slightly later than for the three more northern west coast MPAs and the maximum values were slightly lower. In the March-May period SST was 25-30°C. During the cooler period, again occurring slightly later in the year (August-October) than the more northern MPAs, surface temperatures were 22-24°C (**Figure 13)**. The SST range was greater than found in the MPAs to the north. The time series and climatology indicate that 1998 was the warmest year (**Figure 18)**. No year was dramatically cooler, although 1993 had a cooler summer than usual.

SSC values at Ningaloo were low, although higher than the MPAs to the north (**Figure 64).** The SSC values fluctuated throughout the year. There was little inter-annual variation in SSC (**Figure 29)**. SST was not correlated with SSC (**Figure 78).**

The SST habitat was larger than the size of the MPA for all months and extended offshore in a northwesterly direction from the MPA (**Figure 41)**. However, parts of the MPA were outside the SST habitat defined on conditions at the center of the MPA. This indicates that Ningaloo covers more than one SST habitat. The mean size of the SST habitat area was similar throughout the year (**Figure 61)** reaching a slightly higher size in May **(Table 2**), although the SST habitat values changed throughout the year (**Figure 65**). Overall, the MPA covered 5.71% of the mean SST habitat area (**Table 1)**.

In general the Ningaloo SSC habitat extended in an easterly direction from the center of the MPA (**Figure 52).** The mean size of the SSC habitat was greatest between July-September (**Figure 62**) when the highest SSC values occurred (**Figure 66, Table 3**). Overall, the MPA covered 25.67% of the mean SSC habitat area (**Table 1)**.

The mean and maximum SST habitats were larger than the mean and maximum SSC habitat in all months, although they were of similar size from July-September (**Figure 75, 76)**.

- Great Australian Bight

Highest SST was found during January-March (18-23°C). The coolest months were July-September with surface temperatures between 13-16°C (**Figure 13)**. The time series and climatology indicate no anomalous years, although the seasonal signal was slightly delayed in 1994 (**Figure 19)**.

SSC values were mid-range for the 12 MPAs; higher than the MPAs to the north and lower than those to the south (**Figure 64)**. The SSC values had one of the strongest SSC seasonal signals, with a peak in May and June. There was little inter-annual variation in SSC (**Figure 30)**. SST was not correlated with SSC (**Figure 78).**

The SST habitat was larger than the size of the MPA for all months and extended in an east-west direction from the center of the MPA (**Figure 42)**. The offshore southern portion and inshore northern portion of this MPA were not found within this SST habitat zone, indicating different habitat conditions within the MPA. The mean size of the SST habitat area was similar throughout the year, with a slight peak in September (**Figure 61, Table 2)** when the SST habitat values were lowest (**Figure 65**). Although the size of the MPA was 37.33% of the size of the mean SST habitat area (**Table 1)**, much of the MPA was outside the habitat area. This is not surprising given the size of this MPA, which ranges from the coastal zone to beyond the continental shelf.

In general the SSC habitat extended in all directions from the center of the MPA (**Figure 53)**, with much of the MPA outside the habitat defined at the center of the MPA. The mean size of the SSC habitat was greatest in August (**Figure 62, Table 3**) after the highest SSC values occurred (**Figure 66**). Overall, the MPA was larger than the habitat area; it was 159.05% of the size of the mean SSC habitat area (**Table 1)**.

The mean SST habitats were larger than the mean SSC habitat in all months, although they were of similar size in August (**Figure 75)**. If the maximum size of the habitats is compared, the SSC habitat was larger than the maximum SST habitat in August and September (**Figure 76).**

- Tasmanian Seamounts.

This was the most southern MPA for which SST was obtained. SST was the coolest for any of the MPAs with temperature data. Highest SST was found during January-March (13-17°C) and the coolest months were July-September (10-13°C) (**Figure 13)**. The time series and climatology suggest that warm summers occurred in the same years (1992-94) as cool winters (**Figure 20)**.

SSC values were the highest found for any MPA (**Figure 64)**. The SSC values had a strong SSC seasonal signal, however, in contrast to the MPAs considered so far, the lowest SSC values were in the winter months and the highest occurred in March and October-December (**Figures 12 and 31)**. SST was positively correlated with SSC (r=0.4) (**Figure 78).**

A SST habitat boundary to the south of the MPA was not found because the data did not extend that far south and so that edge was closed using the boundaries on either side. This would tend to underestimate the true size of the habitat. Even so, the SST habitat was larger than the size of the MPA for all months and extended in all directions from the center of the MPA (**Figure 43)**. The mean size of the SST habitat area was similar throughout the year (**Figure 61**) and was small compared to the other MPAs **(Table 2).** There was a slight seasonal signal in the SST habitat values (**Figure 65**). Overall, the MPA covered a mean of 7.31% of the SST habitat area (**Table 1)**.

The SSC habitat area coverage was much more dynamic, extending in different directions from the center of the MPA each month (**Figure 54)**. This reflects the dynamic nature of the ocean currents in this region. The mean size of the SSC habitat was greatest in April and August (**Figure 62, Table 3**), when the SSC habitat values were intermediate (**Figure 66**). Overall, the Tasmanian Seamounts MPA was 2.81% of the size of the mean SSC habitat area (**Table 1)**.

The mean SST habitats were smaller than the mean SSC habitats in all months (**Figure 75**), which was unique amongst the MPAs. This indicates that the SSC environment was more homogenous than the SST environment in this region. If the maximum size of the habitats is compared, the SST habitat was larger than the maximum SSC habitat in only three months (**Figure 76).**

- Macquarie Island

The southerly location of this MPA makes it poorly suited to satellite monitoring. No SST coverage existed in the satellite data set used. Information does exist in other satellite data sets, and could be extracted for this MPA. The differing biases between data sets would make comparisons to other MPAs of limited value.

Although seasonal ice coverage interferes with detection of surface water properties, information on SSC was obtained for the ice-free months. SSC was low compared to the cold-water MPA to the north (Tasmanian Seamounts), and was actually more similar to that of the three northwestern MPAs (Ashmore, Cartier and Mermaid). SSC values increased slightly in November and December (**Figures 12 and 32).**

Macquarie Island SST habitat areas could not be found because the data did not extend that far south.

The SSC habitat area could be determined for nine months of the year and was always within the MPA boundary, indicating that different habitats occurred within the MPA (**Figure 55)**. This MPA had the largest SSC habitat area (**Table 2).** The mean size of the SSC habitat was greatest in October

(**Figure 62**) and the SSC habitat values were similar throughout the year (**Figure 66**). On average, this MPA was 1019% larger than the size of the mean SSC habitat area (**Table 1)**.

The SST habitats could not be compared to the size of the SSC habitat but the size of the SSC habitat by month is still indicated (**Figure 75, 76)**.

- Lord Howe Island

SST had a strong seasonal signal at Lord Howe Island. Highest SST was found during January-March (23-26°C) and the coolest months were July-September (17-21°C) (**Figure 13)**. The warmest years compared to the climatology were 1997 and 1998, and 1992 was the coolest (**Figure 21)**.

SSC was moderate compared with the other MPAs (**Figure 64)**. SSC values were highest in July-October when SST was highest and lowest in January-March when SST was lowest (**Figure 12).** Interannual variation was not obvious in the three years of SSC data (**Figure 33**). SST was strongly negatively correlated with SSC (r=-0.89) (**Figure 78).**

The SST habitat was larger than the size of the MPA for all months and extended more in easterly direction from the center of the MPA (**Figure 44)**. The mean size of the SST habitat area was similar throughout the year (**Figure 61**), but reached greatest size in March **(**Table 2). The value of the habitat area was strongly seasonal (**Figure 65**). The Lord Howe Island MPA covered a mean of 8.87% of the SST habitat area.

In general the SSC habitat extended in different directions from the center of the MPA each month (**Figure 56)**, but the size differed little (**Figure 62**), despite changes in the SSC habitat values (**Figure 66**). Overall, the MPA covered 15.51% of the mean SSC habitat area (**Table 1)**, which was the second largest of the MPA SSC habitats **(Table 3**).

The mean SST habitats were similar in size to the SSC habitat in about half of the months (**Figure 75**) and the SSC habitat was larger than the maximum SST habitat in September (**Figure 76).**

- Solitary Islands

SST had a distinct seasonal signal. Highest SST was found during January-March (23-27°C) and the coolest months were July-October (18-22°C) **(Figure 13)**. The warmest year compared to the climatology was 1998 and 1992 was the coolest **(Figure 22)**.

SSC was high throughout the year compared with the other MPAs (**Figure 10)**. The values found were second highest to those at the Tasmanian Seamounts MPA. Interannual variation was not apparent (**Figure 34**). SST was not correlated with SSC (**Figure 78).**

The mean SST habitat was larger than the size of the MPA for all months and extended away from the center of the MPA (**Figure 45)**. The mean size of the SST habitat area was similar throughout the year (**Figure 61),** although the value of the habitat area changed seasonally (**Figure 65**). The Solitary Islands MPA covered a mean of 4.50% of the SST habitat area (**Table 1)**, which was the smallest for all the MPAs (**Table 2)**.

In general the SSC habitat was larger than the MPA and extended in different directions from the center of the MPA each month (**Figure 57)**, and size differed little (**Figure 62**). There was a seasonal signal to the SSC habitat values (**Figure 66**). Overall, the MPA covered 7.21% of the mean SSC habitat area (**Table 1)**. The mean SSC habitat size at Solitary Islands was the smallest found for any MPA (**Table 3).**

The mean SST habitats were smaller than the SSC habitat only in July and August (**Figure 75**). The maximum SST habitat was smaller than the maximum SSC habitat only in August and September (**Figure 76).**

- Elizabeth and Middleton Reefs

Highest SST was found during January-March (22-28°C) and the coolest months were July-September (17-21°C) (**Figure 13)**. As for the other east coast MPAs, the warmest year compared to the local climatology was 1998, with 1992 the coolest (**Figure 23)**.

The seasonal SSC signal was distinct. SSC was high when SST was low and vice versa (**Figure 10)**. There was an extended period of relatively high values between June-November. The SSC values were moderate with little interannual variation (**Figure 35**). The strongest correlation (negative) between SST and SSC (r=-0.92) was found at this MPA (**Figure 78).**

The SST habitat was larger than the size of the MPA for all months and extended in an easterly direction from the MPA (**Figure 46)**. The mean size of the SST habitat area was highest in March (**Figure 61, Table 2)**; a seasonal signal in the SST habitat values was apparent (**Figure 65**). Overall, this MPA covered 2.58% of the mean SST habitat area (**Table 1)**.

The SSC habitat was also larger than the MPA, and generally extended in all directions from the center of the MPA (**Figure 58).** The mean size of the SSC habitat was greatest in September (**Figure 62, Table 3**) and the SSC habitat values varied seasonally (**Figure 66**). Overall, the MPA covered 7.01% of the mean SSC habitat area (**Table 1)**.

The mean and maximum SST habitats were larger than the mean and maximum SSC habitat in all months, although they were of similar size in September (**Figure 75, 76)**.

- Lihou Reef

Lihou Reef was one of the two warmest MPAs on the east coast of Australia; the other was Coringa-Herald. The seasonal signal was not as distinct as for the southern MPAs, but was similar to the warm water west coast MPAs. The highest SST was found during December-March (23-28°C) and the coolest months were July-September (17-22°C) (**Figure 13)**. As for the other east coast MPAs, the warmest year compared to the local climatology was 1998, while portions of 1991 1993, and 1994 were cooler than the climatology (**Figure 24)**.

The seasonal SSC signal was indistinct with very low SSC values throughout the year (**Figure 10)** and little interannual variation (**Figure 36**). SST was strongly negatively correlated with SSC (r=-0.68) (**Figure 78).**

The Lihou Reef SST habitat was larger than the size of the MPA for all months and extended in all directions from the center of the MPA (**Figure 47)**. The mean size of the SST habitat area was similar for most of the year (**Figure 61, Table 2)** and a seasonal signal in the SST habitat values was apparent (**Figure 65**). Overall, the MPA covered 4.66% of the mean SST habitat area (**Table 1)**.

The SSC habitat was larger than the MPA in some months, and smaller in others. The habitat generally extended in all directions from the center of the MPA, but tended slightly towards the west (**Figure 59).** The mean size of the SSC habitat was greatest in October (**Figure 62, Table 3**) although SSC values were similar throughout the year (**Figure 66**). Overall, the MPA covered an area equal to 155.05% of the mean SSC habitat area (**Table 1)**.

The mean and maximum SST habitats were larger than the mean and maximum SSC habitat in all months (**Figure 75, 76)**.

- Coringa-Herald

This MPA was one of the two warmest on the east coast of Australia, the other was Lihou Reef. The SST patterns were very similar to those found for Lihou Reef. The seasonal signal was not as distinct as for MPAs to the south, but was similar to the west coast MPAs at similar latitudes. The highest SST was found during December-March; SST ranged between 23-28°C. The coolest months were July-September with SST ranging between 17-22°C (**Figure 13)**. As for the other east coast MPAs, the warmest year compared to the local climatology was 1998 (**Figure 25)**.

The seasonal SSC signal was indistinct with very low SSC values throughout the year (**Figure 10)** and little interannual variation (**Figure 37**). SST was weakly negatively correlated with SSC (r=-0.4) (**Figure 78).**

The Coringa-Herald SST habitat was larger than the size of the MPA for all months and extended in all directions from the center of the MPA (**Figure 48)**. The mean size of the SST habitat area was similar for most of the year (**Figure 61, Table 2)** and a seasonal signal in the SST habitat values was apparent (**Figure 65**). Overall, the MPA covered 4.33% of the mean SST habitat area (**Table 1)**.

The SSC habitat was larger than the MPA in some months, and smaller in others. The habitat generally extended in all directions from the center of the MPA, perhaps tending towards the west (**Figure 59).** The mean size of the SSC habitat was greatest in September and October (**Figure 62, Table 3**) just after the slight peak in SSC values (**Figure 66**). Overall, the MPA covered an area equal to 49.82% of the mean SSC habitat area (**Table 1)**.

The mean and maximum SST habitats were larger than the mean and maximum SSC habitat in all months (**Figure 75, 76)**.

Satellite data for rapid assessment

The preceding results show that historical satellite data can provide a description of the environment at the ocean surface. The advantages of satellite data for assessment of MPA surface characteristics are that satellite data (i) covers a wide area at the same time, (ii) covers a reasonable period of time for developing baselines, and (iii) allows information to be obtained for areas that were not previously targeted. That is, the need for a human or an instrument at a particular location is removed. Satellite information can be rapidly considered, and a number of syntheses created to assess surface regions, as shown in this report.

Processing of satellite data is quite involved, access may be restricted, and research accurate data may be 1-2 years old before release. A typical satellite image for SST and SSC for the Australian region may have gaps in coverage, due largely to cloud cover. In some cases these gaps can be filled (Walker and Wilken, 1998). While historical analyses can take place rapidly, the availability of real-time data to the non-research community is restricted, and may be limiting in some applications, such as rapid analysis of a current event.

When *in situ* measurements can be compared with the historical satellite data, rapid real time assessment is possible. Care should be taken when comparing a single *in situ* sample with the satellite data, however, as *in situ* measurements are usually point measurements, and comparison with the spatially averaged measurements from satellites may result in differences. To compare *in situ* measurements, prior knowledge of the historical relationship between the two methods will allow correct inferences to be made. Validation studies should be undertaken by users of the data to allow such comparisons in the future. If access to real time satellite data is possible, then comparisons can also be made to this historical data set. Care should be taken to ensure that data processing is carried out in a consistent fashion, so that biases do not result in spurious differences between the existing and new information.

Some examples of how this historical satellite information might be used in MPA management and performance assessment are offered.

- Information on the SST and SSC signal will indicate the tolerance and habitat usage of indicator species that are found in the MPA region under particular physical conditions. For example, if a species is found in the MPA when the SST is 22°C and not when the SST is 30°C, that information can be used to construct SST habitat preferences for the species. This information can then be further used to decide which other areas may be suitable for the species.
- Information on SSC will allow rapid identification of changes in the productivity of the MPA region. For example, if SSC is anomalously low at some time, then other ecosystem effects may occur, and additional measures for a protected species may be enacted.
- Comparisons between years will allow an understanding of the effect of climate variation on the MPA surface habitat. For example, El Niño years may lead to changes in SSC or SST at some MPAs, with subsequent effects on the biota. Knowledge about the effects in these anomalous years can then be extrapolated to make predictions about the habitats that will be protected if the anomalous climatic conditions persisted, as may occur under global climate change.
- Identification of potential future locations for MPAs is possible based on patterns in the remotely sensed environmental characteristics. For example, if there is always a gap in the SST habitats between Ningaloo and Mermaid Reef, then a pelagic SST habitat may not be protected. Knowledge about the habitats at the

current MPAs will allow identification of habitats and species that do not have some fraction of their habitat protected at some times of the year.

The frequency of important oceanic surface features that are related to productivity, such as fronts and upwelling plumes was not determined for the MPAs because the resolution of available satellite data was inadequate (resolution of 1 km^2 is required, only 9 km^2 resolution data was available for the entire region). Such an analysis could be undertaken with appropriate data.

The direction of water movement can be inferred from remotely sensed sea surface height data, if the seasonal sea surface climatology is added. Because this was not available to the author, and superior models exist, this component was not addressed. Information on the direction and speed of surface water movement in and around each MPA will allow rapid determination of pollution threats to the MPA via advection from sources outside the MPA. In addition, an understanding of water movement will indicate larval dispersal pathways, and potential of the MPA to be a larval source for other regions. These are important considerations in the design of a complete set of comprehensive, adequate and representative MPAs for Australia, and should be addressed in the future.

5. Conclusion

This study has provided historical baselines of two vital signs, satellite SST and SSC, for describing and monitoring the surface environment of twelve Commonwealth MPAs. The surface habitat analyses using SST and SSC allowed the local importance of each MPA in terms of protecting a local pelagic environment to be assessed, and identified additional regions for protection using the distribution of currently protected habitats. This analysis was done rapidly, without the need for detailed fieldwork over the length of the time period that data was available. In this sense, assessment using satellite data is rapid.

Future work in specific MPAs should use relationships between the physical habitat characteristics and the target species (where known), to identify species-specific habitat via remote sensing technology. Multivariate habitat descriptions should also be investigated, and may provide more realistic environmental vital signs.

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7. Appendices

Appendix 1. SST and SSC baseline data.

The statistics that describe the SST and SSC for each MPA for each date are contained in two files submitted with this report.

- SST: MPAsstCommonwealthData10.dat
- SSC: MPAsscCommonwealthData8.dat.

The number portion of the filename represents the number of days between images. Each file is 10 columns wide. The column contents are:

- column 1: MPA number, 1-12;
  1. Ashmore Reef.
  2. Cartier Island.
  3. Mermaid Reef.
  4. Ningaloo.
  5. Great Australian Bight.
  6. Tasmanian Seamounts.
  7. Macquarie Island.
  8. Lord Howe Island.
  9. Solitary Islands.
  10. Elizabeth and Middleton Reefs.
  11. Lihou Reef.
  12. Coringa-Herald.
- column 2: year of image
- column 3: month of image;
- column 4: day of image;
- column 5: number of SST or SSC pixels within MPA with good values;
- column 6: mean SST or SSC in the MPA for that image
- column 7: median SST or SSC in the MPA for that image;
- column 8: maximum SST or SSC in the MPA for that image;
- column 9: minimum SST or SSC in the MPA for that image;
- column 10: standard deviation of SST or SSC values in the MPA for that image;

Appendix 2. Habitat Area Data

The statistics that describe the SST and SSC habitat areas associated with each MPA for each month are contained in two files submitted with this report.

- SST Habitat Areas: HabitatAreaSST.dat
- SSC Habitat Areas: HabitatAreaSSC.dat

The number portion of the filename represents the number of days between images. Each file is 7 columns wide. The column contents are:

- column 1: MPA number, 1-12;
  1. Ashmore Reef.
  2. Cartier Island.
  3. Mermaid Reef.
  4. Ningaloo.
  5. Great Australian Bight.
  6. Tasmanian Seamounts.
  7. Macquarie Island.
  8. Lord Howe Island.
  9. Solitary Islands.
  10. Elizabeth and Middleton Reefs.
  11. Lihou Reef.
  12. Coringa-Herald.
- column 2: year
- column 3: month
- column 4: maximum habitat area for that month (km^2)
- column 5: mean habitat area for that month (km^2)
- column 6: Fraction of the MPA area to the maximum habitat area for the month
- column 7: Fraction of the MPA area to the mean habitat mean area for the month

8. References

Walker, A. E. and Wilken, J. L. 1998. Optimal averaging of NOAA/NASA Pathfinder satellite seas surface temperature data. Journal of Geophysical Research, 103: 12869-12883.