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Tactical Research Fund

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FRDC Project No. 2012/239
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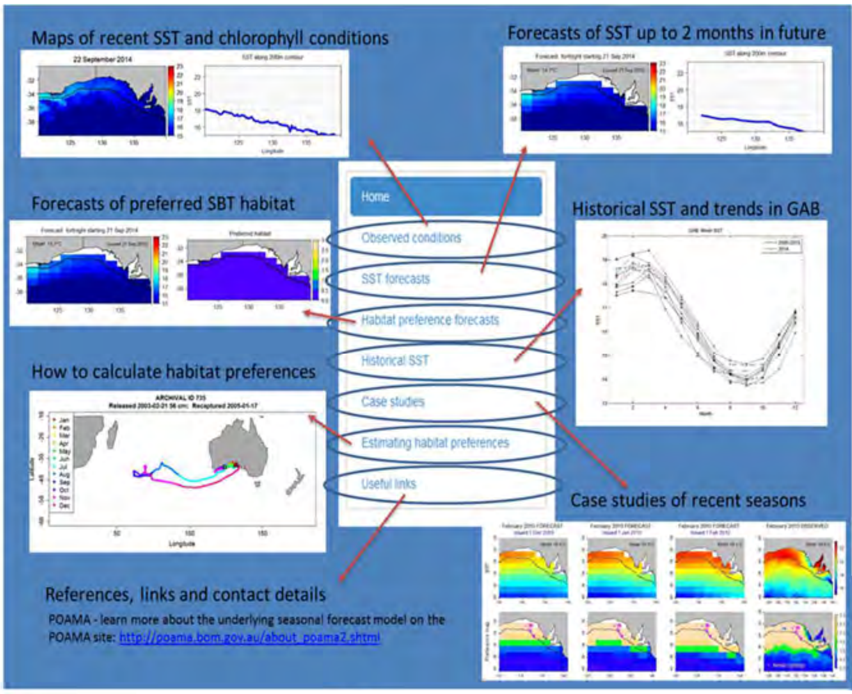

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Australian Government
Bureau of Meteorology

AUSTRALIAN SOUTHERN BLUEFIN TUNA INDUSTRY ASSOCIATION LTD (ASBTIA)

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The ongoing support from the Australian Southern Bluefin Tuna Industry Association (ASBTIA) and industry members through feedback about the project and website was key to the success of this project. Marinelle Basson (CSIRO) was the original principal investigator on the project, and we acknowledge the key role she played in project development and initiation. Thanks to Toby Patterson (CSIRO) who produced the archival tag tracks used in this report, and also provided useful input regarding the habitat preference model. This project was made possible by funding from FRDC with co-investment from CSIRO and contributions from ASBTIA and the Australian Bureau of Meteorology.

Executive Summary

What the report is about

This report describes a collaborative project between CSIRO, the Australian Southern Bluefin Tuna Industry Association (ASBTIA) and the Australian Bureau of Meteorology (BoM), co-funded by the Fisheries Research and Development Corporation (FRDC Project 2012/239). The project aim was to investigate habitat preferences of Southern Bluefin Tuna (SBT) in the Great Australian Bight (GAB) and to provide forecasts of habitat distribution to industry members to aid in their planning operations. An industry-targeted website was developed to deliver the forecasts, and feedback from industry members indicates the success of the project, with overall satisfaction with the content and delivery of information on the website being rated from 8 to 10 out of 10.

Background

The project was initiated by an approach from industry in response to observed changes in spatial distribution of SBT in the GAB through recent fishing seasons. In particular, in the 2012 season, movement of SBT through the GAB was rapid, and fish were distributed further east than usual, resulting in fewer purse-seine catches being taken from fishing grounds commonly used in the previous 20 years. The maximum speed that vessels towing pontoons can travel precludes rapid repositioning in response to fish movement, therefore catching vessels and tow vessels with pontoons need to be positioned in expected catch locations prior to SBT arrival. As such, rapid movements of surface schools and the presence of fish in unexpected locations make fishing operations costly and unpredictable.

In light of these observed changes, information on future ocean conditions and expected distribution of SBT corresponding to these conditions would be valuable to industry. Such information is now available from seasonal forecasting models, such as the BoM’s state-of-the-art Predictive Ocean Atmosphere Model for Australia (POAMA). This model can deliver information regarding future environmental conditions at a timescale of weeks to months. In partnership with the BoM, seasonal forecasting is being used in marine fishery and aquaculture operations in Australia, including wild tuna and farmed salmon and prawns, to reduce uncertainty and manage business risks. Several forecast variables appropriate for SBT in the GAB are available, including sea surface temperature (SST), but the performance of these forecast products had not yet been assessed in the GAB.

By combining seasonal environmental forecasts (such as forecasts of SST) with habitat preference information for a species, species-specific forecasts of habitat distribution can be made. This approach has already proven effective as part of the Australian Fisheries Management Authority East Coast SBT Spatial Management project, where a habitat preference model for SBT based on surface and sub-surface ocean temperatures (conditioned with electronic tag data) has been used to produce forecasted maps of predicted SBT distribution off the east coast of Australia.

As part of a recently completed FRDC project, data from archival tags deployed on juvenile SBT were used to explore the environmental variables influencing their spatial distribution. Habitat preference models for SBT were developed based on the variables found to have the greatest influence, namely SST and chlorophyll *a*.

Objectives

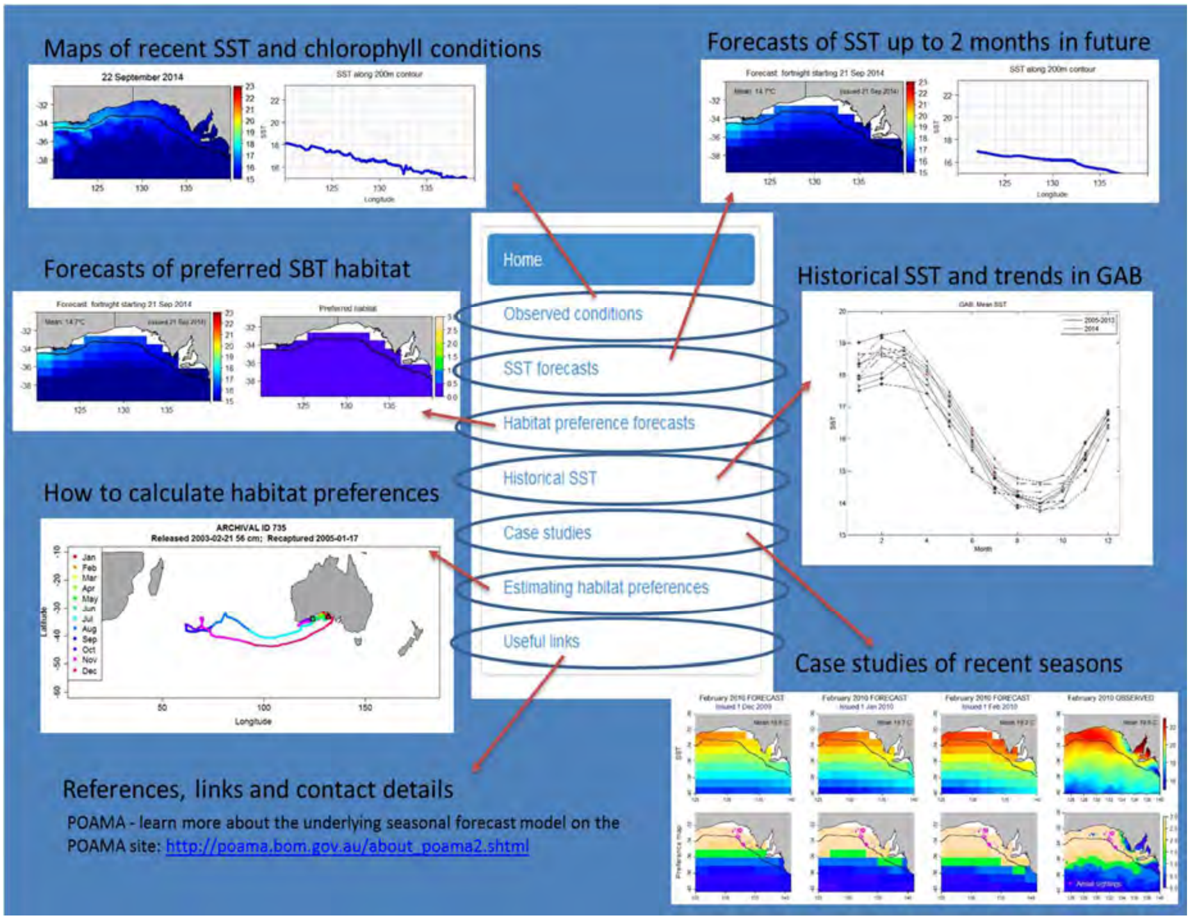
The first objective of the current project was to refine the habitat preference model to make it specific for SBT in the GAB during the key months of the fishing season (Objective 1). The next goal was to use the habitat preference model to produce maps of expected SBT habitat corresponding to recent environmental conditions (Objective 2). The intermediate forecasting goal (Objective 3) was to produce forecasts of useful environmental variables (e.g. SST) in the GAB, and to evaluate the skill of these forecasts. If the skill proved to be satisfactory, then the ultimate goal was to use the environmental forecasts in conjunction with the habitat preference model to forecast SBT habitat distribution in the GAB in future (Objective 4). Finally, to ensure these forecasts were easily available to industry members, the aim was to deliver both the environmental and habitat forecasts via an industry-specific website, and to develop and refine the website in response to ongoing dialogue with industry representatives.

Methods and Results

GAB-specific habitat preference models were developed based on SST data alone and on SST and chlorophyll *a* data combined. In developing these models, newly available position estimates from archival tag data were used that were derived during the course of the project using a method developed by colleagues at CSIRO. The skill of the habitat models was evaluated using historical aerial survey data to see how well the models could predict locations of SBT sightings. The results showed that the habitat preference model based on SST data alone provides useful information about SBT distribution, and that the addition of chlorophyll *a* to the model provides important additional information. The range of SST values preferred by SBT in the GAB is 19-22°C. The preferred range of chlorophyll *a* values depends on the value of SST, but is generally from 0.1-0.3 mg/m^3. Knowing these preferences allows us to determine regions of the GAB where the relative abundance of fish is expected to be greatest. Using both the model based on SST alone and the model based on SST and chlorophyll *a* combined, maps were produced showing the areas of preferred SBT habitat in the GAB corresponding to recently observed conditions.

The skill of the seasonal forecasting model (POAMA) at forecasting SST in the GAB was assessed by correlating historical forecasts of SST ("hindcasts") with observed SST over the period 1982-2010 using the Pearson correlation coefficient. The results showed that the model has skill out to approximately two months in the GAB during the months of the fishing season. Thus, the habitat preference model based on SST data was used in conjunction with POAMA forecasts of SST to produce forecasts of preferred SBT habitat in the GAB up to two months in future. Unfortunately, chlorophyll *a* is not one of the variables currently forecasted by POAMA so habitat forecasts based on the model with SST and chlorophyll *a* combined could not be produced.

A dedicated website (www.cmar.csiro.au/gab-forecasts) was developed to deliver the forecasts of environmental conditions and preferred SBT habitat to industry, and it was updated throughout the project based on feedback from industry members. Information on recent and historical environmental conditions in the GAB was also included, as this was of interest to industry. Below is a schematic of the website, showing the types of information that can be found on each of the website pages.



Implications for relevant stakeholders

An important implication of this project for stakeholders is that it should improve their ability to plan fishing operations in the GAB based on forecasts of environmental conditions and SBT habitat distribution in the upcoming weeks to months. This represents an opportunity for cost savings in the harvest of this quota-restricted resource. It is important for industry representatives to have ongoing conversations around the strengths and limitations of forecasts, as this will lead to greater awareness of risk-based decision making. As with weather forecasts, seasonal forecasts can still be wrong – but sustained use is likely to lead to more positive outcomes than just assuming “average conditions” to plan business operations. The use of seasonal forecasts in supporting effective decision making may also represent a stepping stone to improve decision making and industry resilience at longer timescales.

Recommendations

To ensure that the forecasting system developed in this project continues to support the SBT industry in future, we recommend ongoing evaluation of the use of the forecast system by industry participants via feedback from ASBTIA. The habitat preference model should also be updated within the next 3-5 years, as continued change in environmental conditions and fish response may alter habitat preferences. An attempt to make a direct calculation of industry cost savings as a result of improved planning around future environmental conditions, as provided by seasonal forecasting, would be useful in deciding future investment by other seafood sectors.

Keywords

Southern Bluefin Tuna, *Thunnus maccoyii*, seasonal forecasting, habitat model, environmental preferences, economic efficiency

Introduction

Changes in the spatial distribution of Southern Bluefin Tuna (SBT; *Thunnus maccoyii*) in the Great Australian Bight (GAB) have been observed through recent fishing seasons (December to March). In particular, in the 2012 season, movement of SBT through the GAB was rapid, and fish were distributed further east than usual, resulting in less than 15% of purse-seine catches being taken from fishing grounds commonly used in the previous 20 years. The maximum speed that vessels towing pontoons can travel precludes rapid repositioning in response to fish movement, therefore catching vessels and tow vessels with pontoons need to be positioned in expected catch locations prior to SBT arrival. As such, rapid movements of surface schools and the presence of fish in unexpected locations make fishing operations costly and unpredictable. This project was developed in direct response to an approach from the Australian Southern Bluefin Tuna Industry Association (ASBTIA) and its industry representatives, who, as a result of the recently observed changes, recognized the need for scientific support to improve operational planning for ranching in the SBT purse-seine fishery.

Seasonal forecasting models, such as the Bureau of Meteorology's state-of-the-art Predictive Ocean Atmosphere Model for Australia (POAMA), deliver information regarding future environmental conditions at a timescale of weeks to months (e.g. Spillman and Alves 2009). Forecast variables include water temperature, rainfall and air temperature, and are considered useful up to approximately 4 months into the future, depending on the region and season of interest. Such information can help improve decision making for a range of marine industries. For example, seasonal forecasting is currently being used in marine fishery and aquaculture operations in Australia, including wild tuna and farmed salmon and prawns, to reduce uncertainty and manage business risks (Hobday et al. 2014). Seasonal forecasts are useful when a range of options are available for implementation in response to the forecasts. The use of seasonal forecasts in supporting effective marine management may also represent a useful stepping stone to improved decision making and industry resilience at longer timescales.

As a next step, species-specific forecasts of habitat distribution can be made by combining these seasonal environmental forecasts with biological habitat preference data. This approach has already proven effective as part of the Australian Fisheries Management Authority (AFMA) East Coast SBT Spatial Management project, where a habitat preference model for SBT based on surface and sub-surface ocean temperatures (conditioned with electronic tag data) has been used to produce real-time and forecasted maps of predicted SBT distribution off the east coast of Australia (Hobday et al. 2011). The real-time maps are used by fishery managers to restrict access of fishers not holding SBT quota to areas with high predicted SBT distribution, whereas the forecasted maps provide managers and fishers with valuable insights into future habitat distributions for the upcoming months to better inform operational decisions.

As part of a recently completed FRDC project – Spatial interactions among juvenile Southern Bluefin Tuna at the global scale: a large scale archival tag experiment (Basson et al. 2012) – data from archival tags deployed on juvenile SBT were used to explore the environmental variables influencing their spatial distribution. Habitat preference models were developed based on the variables found to have the greatest influence, namely sea surface temperature (SST) and chlorophyll *a*. As part of the current project, we aim to refine the habitat preference model for juvenile SBT in the GAB during the key months of the fishing season. Once a GAB-specific habitat preference model has been established, it can be used to generate maps of predicted SBT distribution corresponding to current and forecasted environmental conditions in the GAB. Forecasts of influential environmental variables should allow fishers and managers to use their existing knowledge of fish behaviour to better plan fishing operations in any year, not just unusual years. Forecasts of fish habitat will further aid this planning and improve strategic fishing skills, leading to increased efficiency/profitability.

In summary, this project has been developed in response to the needs of industry for a better understanding of fish movement and distribution in the GAB. Maps showing forecasts of the environmental variables that affect SBT distribution and of the predicted SBT habitat distribution corresponding to these variables will be delivered through a dedicated website. Input and feedback from industry will be sought throughout the project to ensure that the forecasts and website meet their needs.

Objectives

The objectives of the project, as agreed in the project contract, are:

1. Historical analysis of archival tag data in the GAB to generate habitat preferences

2. Now-casts of habitat distribution based on habitat preferences

3. Forecasts of ocean variables on a monthly time scale

4. Forecasts of SBT habitat distribution in the GAB

Methods

Producing forecasts of preferred SBT habitat in the GAB involved a number of steps. First, archival tag data from juvenile SBT were used to provide historical information on the location of SBT in the GAB. This location information was used to develop a habitat preference model for SBT in the GAB based on environmental variables previously shown to influence SBT distribution. Next, the habitat preference model was used in conjunction with an environmental forecasting model to produce forecasts of preferred habitat weeks to months in future. The ability of the habitat preference model to predict historical fish locations and of the environmental forecasting model to reproduce past observed conditions were evaluated. Forecasts of environmental conditions and preferred SBT habitat were delivered to industry through a dedicated website, which was updated throughout the project based on feedback from industry. All of these steps are described in detail below.

Archival tag tracks

Tracks estimated from archival tags deployed on juvenile SBT were used in determining their habitat preferences in the GAB. Data were available from fish tagged in 1998-2008 at ages 1-4 and generally recaptured 1-2 years later. Of the 826 releases, there were 148 recaptures, 78% of which occurred in the GAB (Figure 1).

To develop the habitat preference model, we required estimates of daily position (latitude and longitude) for each recaptured fish using data recorded on its archival tag. A number of methods exist for estimating location from archival tag data, but the method used for this project was developed at CSIRO using methods similar to Pedersen et al. (2011); refer also to Chapter 7 of Basson et al. (2012). It can be summarized as follows:

- The method uses a discrete space and time state-space model with data inputs:
    - approximate longitude estimates (calculated from light recorded by the tag),
    - sea surface temperature (SST) recorded by the tag (compared to remote sensing SST data).

- The error distributions used for the data inputs are as follows:
    - Error in the longitude estimates is derived from tags at known locations and assumed to follow a Gaussian + t-distribution mixture.
    - Error in SST is modelled using a Gaussian distribution accounting for bias in sensors.
- The process model is a simple random walk/diffusion model.
- The model output is the posterior probability of the fish being in each of the possible discrete space grid locations at each half-day time step.
- The estimated positions used in the habitat model are the weighted average of the posterior probabilities across space at each time step.

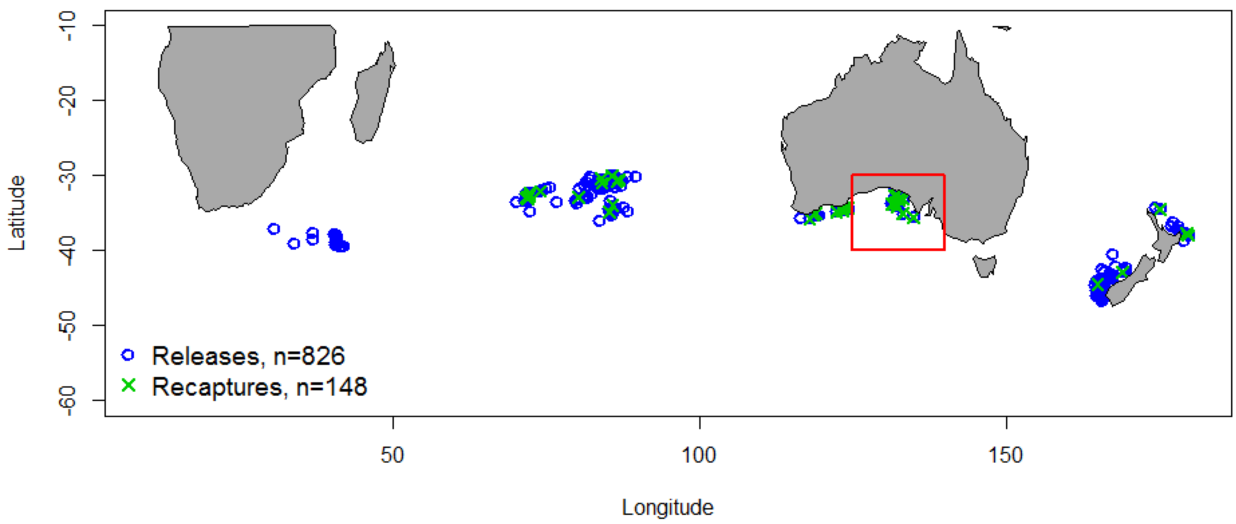


Figure 1. Release and recapture locations of juvenile Southern Bluefin Tuna tagged with archival tags between 1998 and 2008. The red box delineates the region defined in this project as the Great Australian Bight.

Habitat preference model

Methods to explore the habitat preferences of juvenile SBT across their geographical range were developed as part of a previous FRDC project "Spatial interactions among juvenile Southern Bluefin Tuna at the global scale: a large scale archival tag experiment” (Basson et al. 2012). For the current project, we used the same approach but applied it to a more specific region and time period. The steps involved are as follows:

1) Choose the area of the ocean and the time period from which data will be used to develop the habitat model.

    - We used the Great Australian Bight between 30-40°S and 125-140°E (red box in Figure 1) for months January-March (when the majority of juveniles are in the area) in years 1998-2009 (all years for which we have archival tag data).

2) Determine the environmental variables to include in the preference model, and the spatial and temporal resolution to use.

    - Based on findings in Basson et al. (2012), we chose to include SST and chlorophyll *a*.

    - We used a spatial resolution of 0.1° latitude by 0.1° longitude, and a temporal resolution of a month.

3) Get the environmental data for the ocean within the area and time period of interest at the spatial and temporal resolution chosen.

    - We extracted SST (source: CSIRO 3-day composite) and chlorophyll *a* (source: SeaWiFS) data for the GAB at the resolution the product was available, then averaged over a 0.1°x 0.1° grid in each Jan, Feb and Mar of 1998-2009.

    - Note that chlorophyll *a* tends to have a highly right-skewed distribution, so we use the logarithm of the data in the model, which we will denote by log(chl *a*).

4) Get the subset of environmental data for only those locations where fish were found within the area and time period of interest.

- We used SBT archival tag tracks to determine locations where fish were found within the GAB during each Jan, Feb and Mar of 1998-2009, then extracted the subset of the ocean SST and log(chl *a*) datasets corresponding to these locations and time periods.

5) Compare the environmental data at fish locations with the environmental data from the ocean to see which conditions the fish tend to 'prefer'.

   a) Define suitable bins for the environmental data sets.

      - We used 0.5°C bins for SST and 0.25 log(mg/m^3) bins for log(chl *a*).

   b) Divide the proportion of fish observations in a given bin by the proportion of ocean observations in that bin.

   c) If the value is greater than 1, the conditions in that bin are “preferred” (i.e., they are found in greater proportion in the fish data than in the ocean data).

   d) Over all bins, this is referred to as the preference curve if there is just one environmental variable (e.g. SST), or as the preference surface if there are two environmental variables (e.g. SST and log(chl *a*)).

   e) Steps (b)-(d) are illustrated in Figure 2 when only SST is used in the preference model (giving a one-dimensional preference curve), and in Figure 3 when both SST and log(chl *a*) are used (giving a two-dimensional preference surface).

6) Use the preference curve (or surface) to determine the regions of preferred SBT habitat in the GAB for any given time period (e.g. January 2007).

   a) Extract the environmental conditions for that time period.

   b) Look up the preference value corresponding to the environmental conditions at each location.

c) Map the preference values to visualize areas of preferred habitat. For example, Figure 4 shows a map of SBT preferred habitat for January 2007 based on SST only; Figure 5 shows the same but for preferences based on both SST and log(chl *a*).

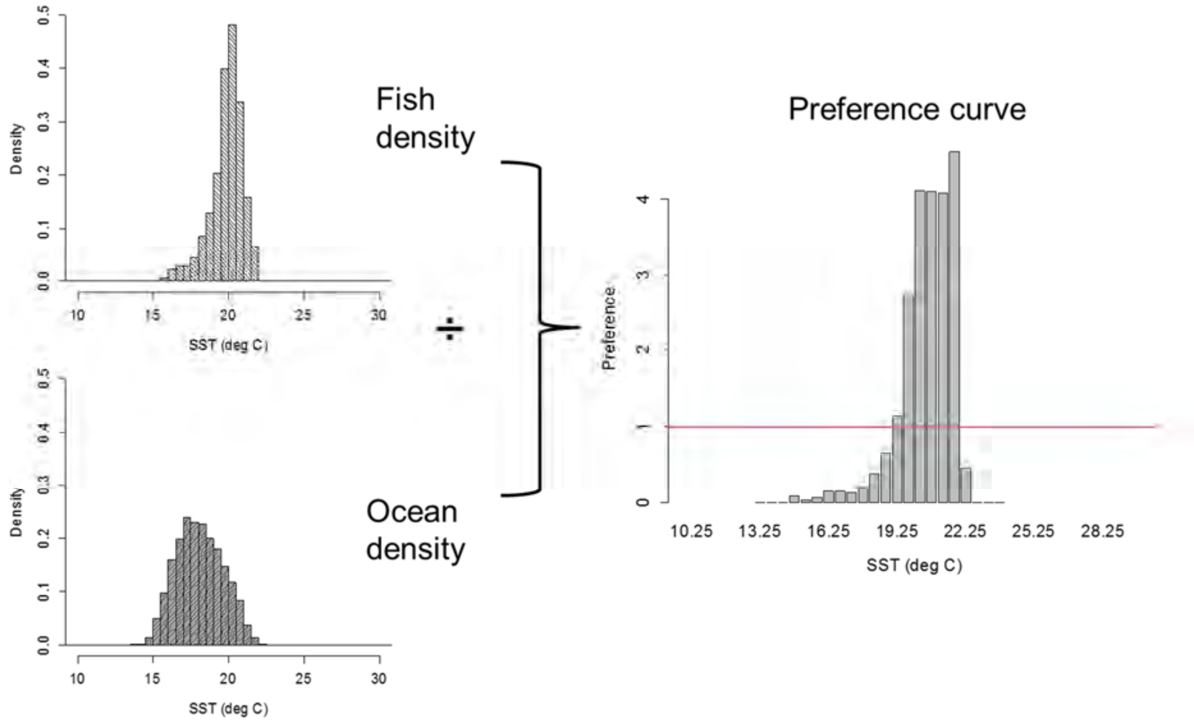


Figure 2. Illustration of determining habitat preferences of SBT in the GAB based on SST data only. The top left shows the distribution (density) of SST values at all locations where fish were found in the GAB during Jan-Mar of 1998-2009 (based on archival tag data). The bottom left shows the distribution of all SST values present in the GAB during Jan-Mar of 1998-2009. The right shows the preference curve derived by dividing the fish distribution by the ocean distribution, where a value > 1 indicates the temperature is preferred (i.e. it is found in greater proportion in the fish distribution than in the ocean distribution).

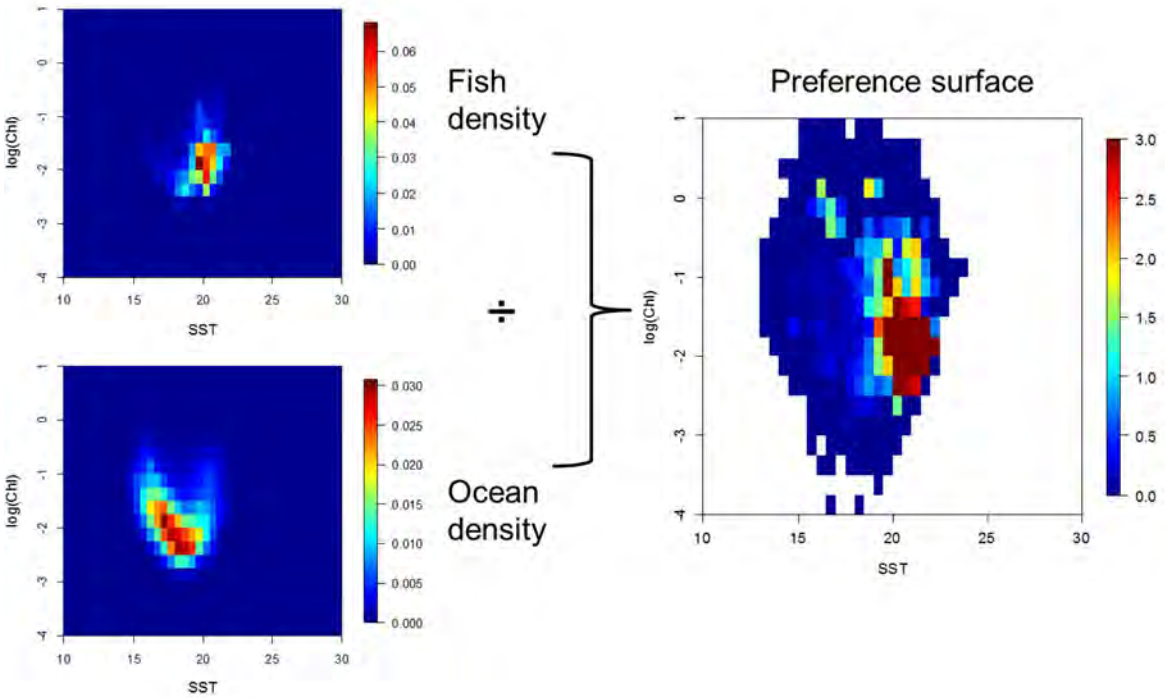


Figure 3. Illustration of determining habitat preferences of SBT in the GAB based on SST and log(chl *a*) data combined. It is analogous to Figure 2 except that the distributions are now two-dimensional.

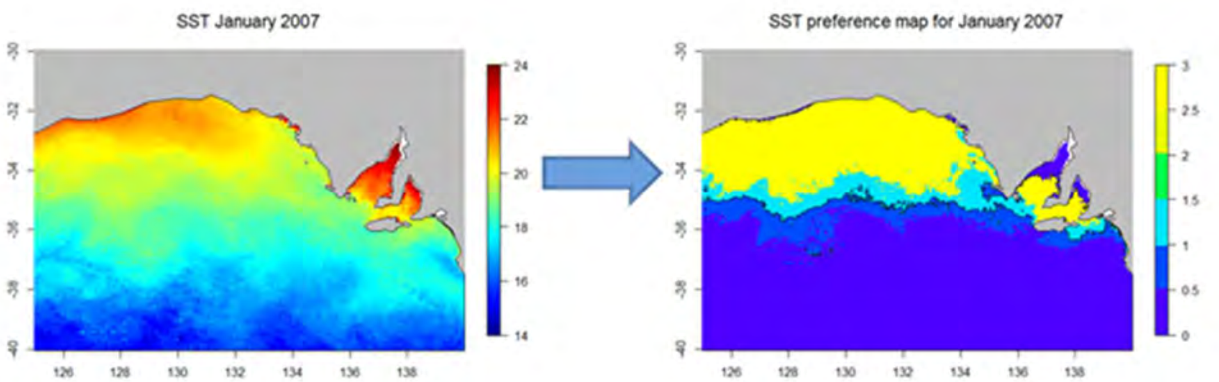


Figure 4. Map of SST data for January 2007 (left) and the corresponding map of SBT preferred habitat based on SST only (right). Preference values > 1 indicate preferred habitat.

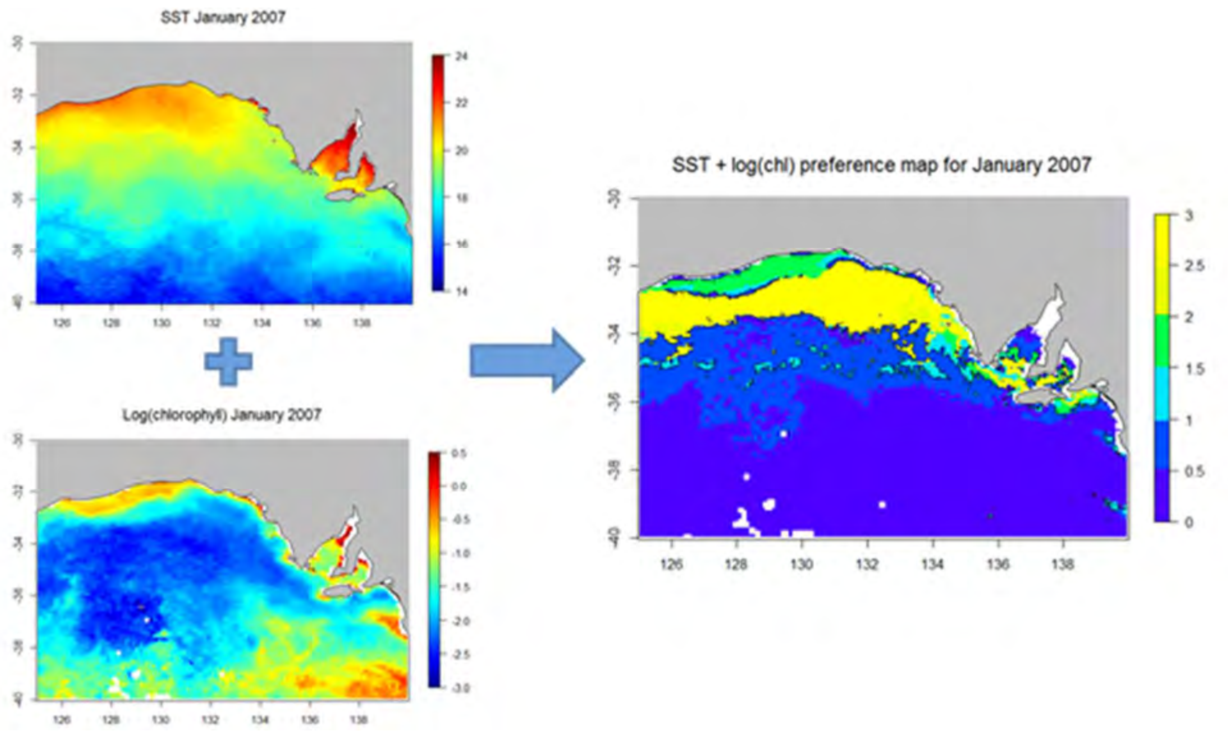


Figure 5. Map of SST data (top left) and log(chlorophyll a) data (bottom left) for January 2007, and the corresponding map of SBT preferred habitat based on SST and log(chl *a*) combined (right). Preference values > 1 indicate preferred habitat.

In order to evaluate how well the habitat preference model predicts the distribution of SBT in the GAB, we use historical aerial survey data. An annual aerial survey of the GAB has been conducted in January-March of 1993-2000 and 2005-present in which trained observers search the region shown in Figure 6 for schools of SBT. For each month and year for which we have survey data, we can compare the locations where fish were spotted with the areas predicted to be preferred habitat. We chose to use aerial survey data to evaluate the habitat model instead of catch data because catch locations can be dependent on factors such as distance from Port Lincoln, vessel positioning and tow speed, and other economic considerations.

The proportion of fish spotted within areas of preferred habitat is not a sufficient measure alone to evaluate performance of the habitat model because the entire survey area may have been deemed preferred habitat. Thus, for each month and year, we divide the proportion of fish (total biomass) spotted within areas of preferred habitat by the proportion of the total survey area considered to be preferred habitat to get a "score" for that month and year. A score greater than 1 suggests the habitat preference model is informative; i.e. fish are found in greater proportion in areas predicted to be preferred habitat than if they were just randomly distributed (which would give a score equal to 1).

As an illustration, consider January 2007. A map showing the areas of preferred habitat for this month based only on SST is given in Figure 6 and based on both SST and log(chl *a*) in Figure 7, with the aerial survey sighting locations overlaid. When the habitat model based only on SST was used, 100% of the fish biomass spotted was within preferred habitat but almost all of the survey area (95%) was estimated to be preferred, so the score was 1.0/0.95=1.05. When the model based on both SST and log(chl *a*) was used, much less of the survey area (73%) was considered preferred, but 96% of fish biomass was still spotted within preferred habitat, so the score increased to 0.96/0.73=1.32.

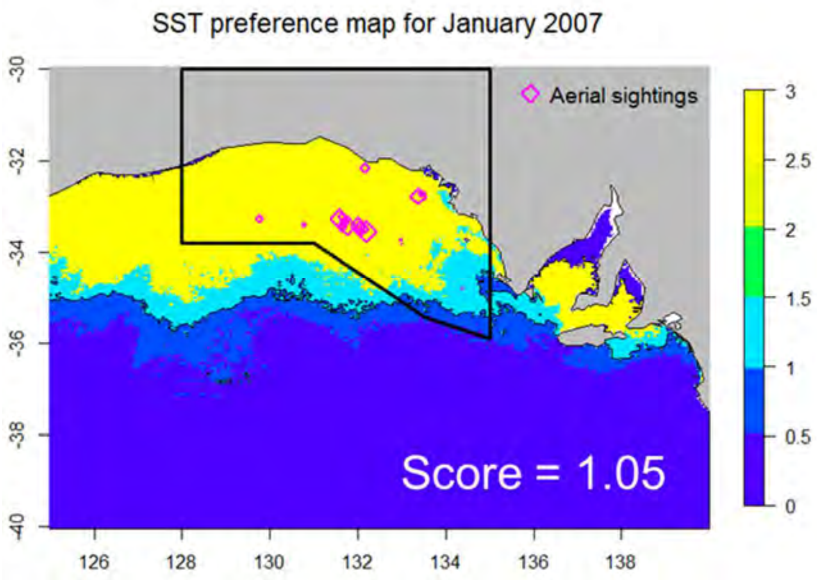


Figure 6. Map showing areas of preferred SBT habitat in January 2007 based on SST data only. Values > 1 indicate preferred habitat. Aerial survey sightings of SBT made in January 2007 are overlaid (pink diamonds, where size of symbol is proportional to biomass of sighting). The score is a measure of how well the habitat preference model predicts SBT distribution; values > 1 indicate the model is informative (see text for details).

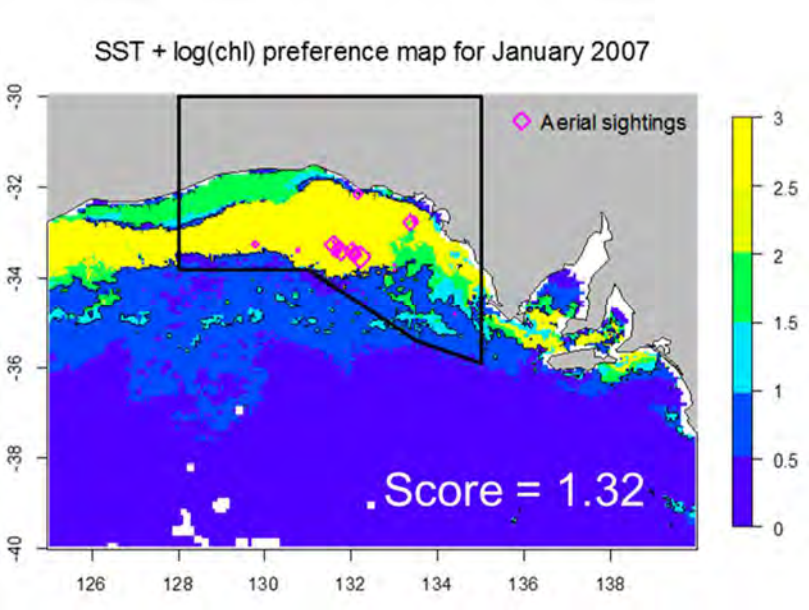


Figure 7. Map showing areas of preferred SBT habitat in January 2007 based on both SST and log(chl *a*) data. See Figure 6 caption and text for further details.

Seasonal forecasting model

POAMA (Predictive Ocean Atmosphere Model for Australia) is a global ocean-atmosphere ensemble seasonal forecast system run operationally at the Australian Bureau of Meteorology since 2002 (http://poama.bom.gov.au/about_poama2.shtml). It comprises a coupled ocean-atmosphere model and data assimilation systems for the initialisation of the ocean, land and atmosphere (Figure 8) (Spillman & Alves 2009). The ocean model grid resolution in the Great Australian Bight domain (30-40°S, 110-145°E) is approximately 90-110 km north-south and 200 km east-west, with upper vertical layers 15 m deep and increasing with water depth. POAMA forecasts a number of environmental variables, but for this project we use only the forecasts of sea surface temperature (SST).

A 33 member ensemble of retrospective multi-week forecasts (hindcasts) was generated by starting the model (POAMA v2) 33 times on the 1st, 11th and 21st of each month for the period 1982-2010, initialised only with data available before the start date and running forward in forecast mode for four months. Initial conditions are provided by two separate data assimilation schemes: an atmosphere/land initialisation system (ALI; Hudson et al. 2011) and an ensemble ocean data assimilation system (PEODAS; Yin et al. 2011). In this study we have focused on only the overall ensemble mean forecast, the average of the 33 ensemble members.

Forecast lead-time is defined as the time elapsed between the model start date (date the model forecast is issued) and the forecast date. In this application we have used forecasts for the first fortnight (f1: mean of the first 14 daily forecasts), second fortnight (f2: mean of the second 14 daily forecasts), and the first two calendar months (m1 and m2) from the model start date. For the monthly forecasts, the first calendar month (m1) is always the next month after the forecast start date, with the second month (m2) being the month following m1. For example, for a forecast starting on 11 February, f1 refers to the forecast for the period 11-24 February, f2 to 25 February-10 March, m1 to 1-31 March and m2 to 1-30 April. Generally forecast accuracy is highest for shorter lead-times (f1 and f2) and decays as forecasts are made further into the future (i.e. increasing lead-time).

POAMA SST anomalies (SSTA) were created for f1, f2, m1 and m2 lead-times by removing the appropriate fortnightly or monthly model climatology from forecast SST values. The model climatology is the long-term fortnightly or monthly mean SST for 1982-2010, computed relative to start date and lead-time, and is removed from SST values to reduce the effects of any model bias (Stockdale 1997). To assess the accuracy of the model SSTA forecasts, model skill is calculated by correlating model SSTA ensemble mean values with observed monthly SSTA values in both space and time over the 1982-2010 period using the Pearson correlation coefficient (Spillman & Alves 2009). The observed dataset is the PEODAS ocean reanalysis, which assimilates satellite and *in situ* data using a sophisticated pseudo ensemble Kalman filter approach on the ocean model grid (Yin et al. 2011). The SSTA forecasts were then scaled by adding the appropriate fortnightly or monthly observed climatology, here derived using PEODAS, to produce a mean adjusted SST forecast dataset that could be input to the habitat distribution model.

Note that at the start of the project, an earlier version of POAMA (POAMA v1) was available. This previous version only provided SST forecasts at monthly lead-times (e.g. m1, m2), not fortnightly (f1, f2). Between the first and second fishing seasons of this project, the new multi-week version (POAMA v2) became available. As such, we redid the skill evaluation for the new system and revised the forecasts being delivered to industry to include fortnightly as well as monthly forecasts.

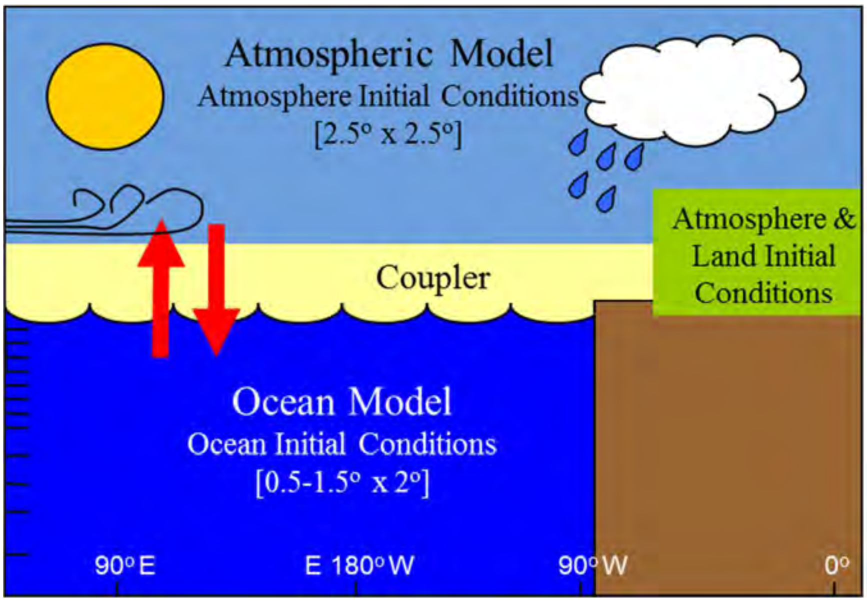


Figure 8. Schematic of the Bureau of Meteorology's Predictive Ocean Atmosphere Model for Australia (POAMA).

Habitat forecasts

Just as we can estimate regions of preferred SBT habitat in the past using observed environmental conditions, we can predict regions of preferred SBT habitat in future using forecasts of environmental conditions. In particular, we can use SST forecasts produced by POAMA to make predictions of where SBT are likely to be distributed in the GAB in the upcoming weeks to months. The usefulness of these habitat forecasts will depend on the skill of the SST forecasts for the time of year and lead-time in question. Unfortunately, POAMA does not forecast chlorophyll, so the habitat forecasts can only be made based on SST data, not on SST and log(chl *a*) combined.

Delivery of results to industry

Forecast delivery was implemented with an industry-specific website, with layout and information provided based on discussion with industry representatives over the course of the project. Visits to Port Lincoln by the technical project team complemented the on-ground frequent discussions facilitated by the industry liaison officer. These discussions shaped the material presented alongside the forecasts on the website. Formal feedback on how forecasts were used in the first season was also elicited with a short survey delivered in person. This survey covered the types of decisions that were influenced, and general satisfaction with the forecast explanation, development and delivery.

Results and Discussion

Archival tag tracks

Not all of the recaptured archival tags recorded data that was useful for estimating position. Using the geolocation method described in the Methods section, position estimates were obtained for 81 of the tags, and 68 of these had positions estimates that were in the region of the GAB used in developing the habitat preference model (30-40°S, 125-140°E). Figure 9 shows an example track estimated from the archival tag data for a single fish, and Figure 10 shows all position estimates used in calculating SBT habitat preferences for the GAB.

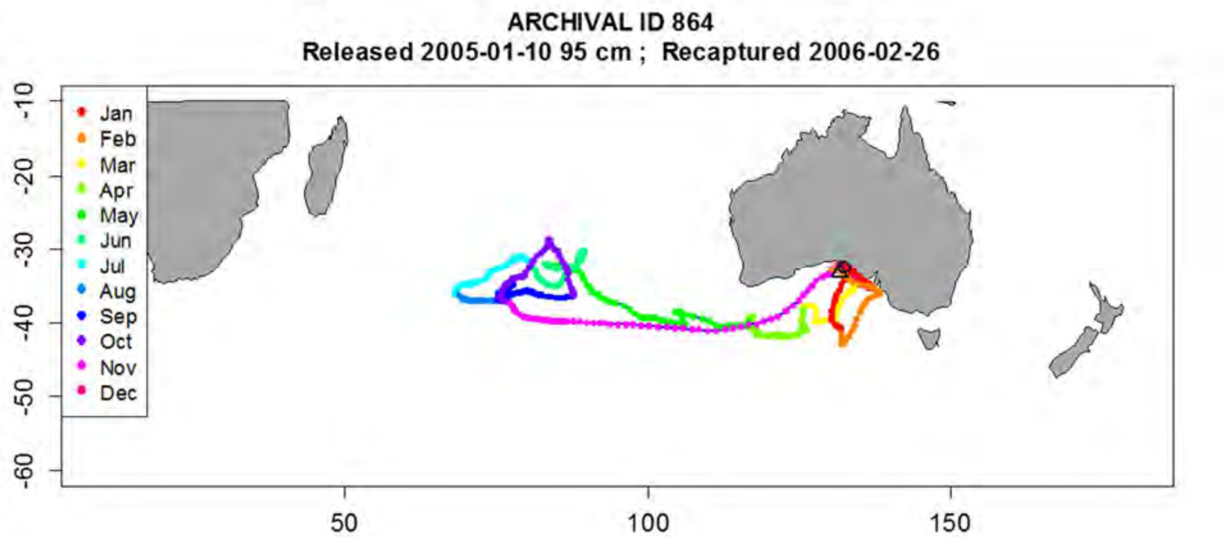


Figure 9. Track estimated from the archival tag data for a fish tagged and recaptured on the dates given in the map title. The open black circle shows the release location; the open black triangle shows the recapture location.

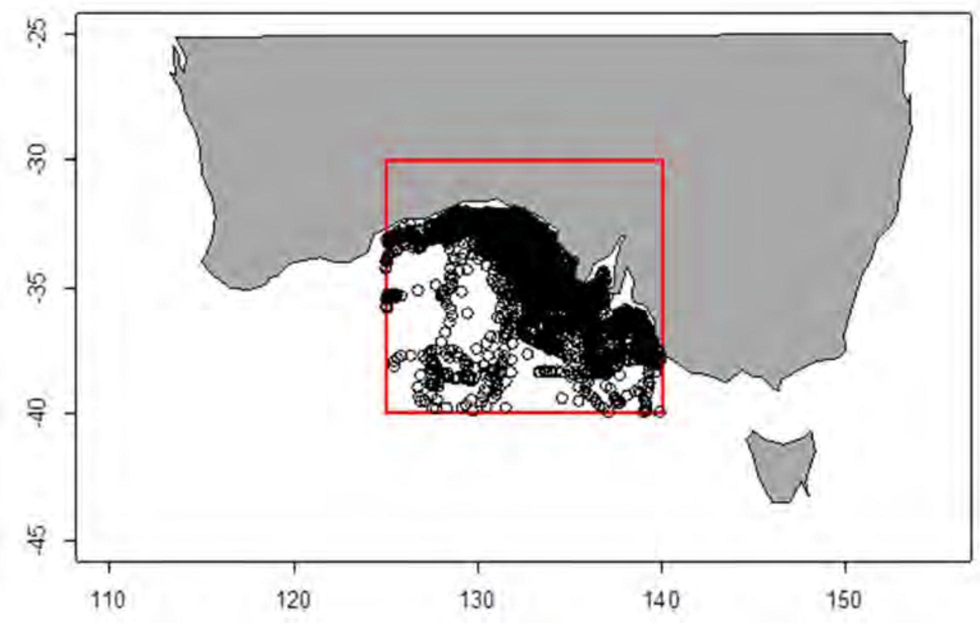


Figure 10. All SBT position estimates from archival tags used in the habitat preference model; i.e. all positions estimates that were within the GAB (defined by the red box) during Jan-Mar of 1998-2009.

Habitat preference model

Based on the habitat model using only SST data, the range of SST values preferred by SBT in the GAB is 19-22°C (i.e., the preference values corresponding to these temperatures are greater than 1; see Figure 2). Based on the model using both SST and log(chl *a*), the levels of chlorophyll preferred by SBT depends on the value of SST, with higher chlorophyll levels tending to be preferred when SST is in the lower end of its preferred range (Figure 3). For instance, when SST is 20-21.5°C, preferred log(chl *a*) levels range from -2.5 to -1.25 (0.08 to 0.29 mg/m^3 on the linear scale); however, when SST is 19-20°C, preferred log(chl *a*) levels range from -2.25 to -0.75 (0.11 to 0.47 mg/m^3 on the linear scale). Examples of habitat preference maps showing areas of expected SBT distribution for January 2007 were given in Figure 6 for the model using only SST and in Figure 7 for the model using SST and log(chl *a*).

Error! Not a valid bookmark self-reference. provides a summary of the scores to evaluate how well the habitat preference models, with only SST and with SST plus log(chl *a*), perform at predicting the locations of aerial SBT sightings in each year and month the aerial survey was conducted. For the model with only SST, all months and years except two had scores greater than 1. For the model including log(chl *a*) data, all months and years except one had scores greater than 1, and all months and years except three had higher scores compared to the model with only SST data. This suggests that, while SST data alone provide useful information about the distribution of SBT in the GAB, the addition of chlorophyll provides important additional information. Unfortunately, chlorophyll is not one of the variables currently forecasted by the seasonal forecasting system being used here (POAMA), and therefore cannot be used in predicting future habitat distribution of SBT.

Table 1. Scores indicating how well the habitat preference models with SST only and with SST plus log(chl *a*) do at predicting the distribution of SBT aerial sightings in each year and month of the survey. Scores above 1 indicate the model is informative. Yellow shading: Score ≥ 1. Green shading: model with chlorophyll and SST has higher score than model with SST only. Red shading: Score < 1. Note: The chlorophyll product we use was not available prior to 1998, nor in 2008; also no SBT were spotted during the aerial survey in March 1996.

	JANUARY		FEBRUARY		MARCH	
YEAR	SST	+CHL	SST	+CHL	SST	+CHL
1994	1.79	-	1.38	-	1.18	-
1995	0.43	-	1.16	-	1.91	-
1996	2.35	-	1.24	-	-	-
1997	1.27	-	1.03	-	1.18	-
1998	1.39	1.42	1.05	1.11	1.11	1.42
1999	1.17	1.28	1.26	1.40	1.55	1.72
2000	1.73	1.83	1.05	1.15	1.06	1.09
2005	1.20	1.42	1.01	1.38	1.41	1.83
2006	1.16	1.30	1.32	1.59	1.08	1.26
2007	1.05	1.32	1.05	1.10	1.08	1.19
2008	1.10	-	1.57	-	1.02	-
2009	1.01	1.09	1.10	1.21	0.93	1.17
2010	1.02	1.18	1.22	1.33	1.10	1.12
2011	1.00	0.53	1.07	1.29	2.31	2.28
2012	1.01	1.27	1.02	1.13	1.01	1.09
2013	1.06	1.22	1.02	1.24	1.03	1.01
2014	1.02	1.02	1.03	1.08	1.03	1.06

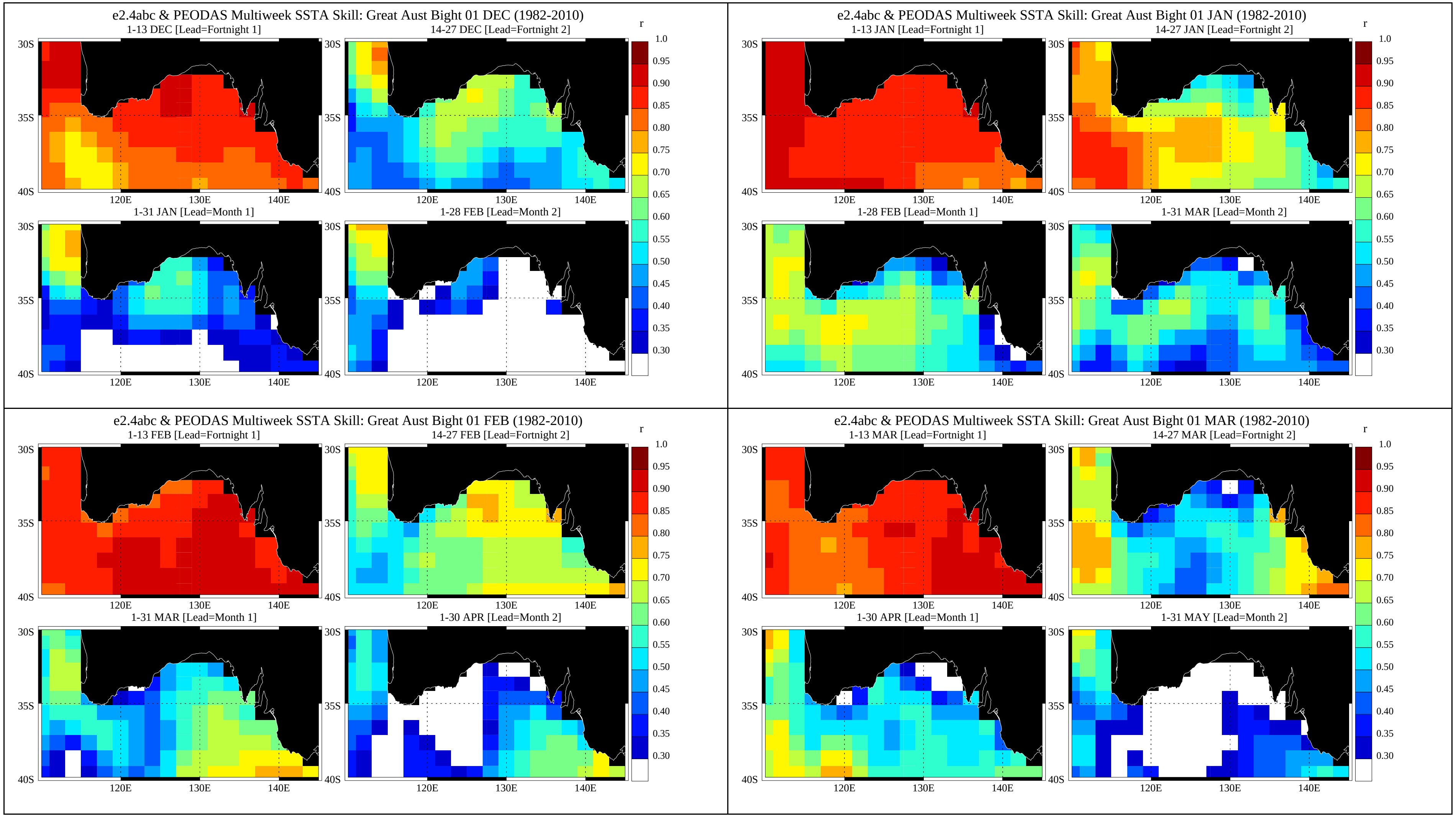
In Basson et al. (2012), where the habitat preference model for SBT was first developed, a preliminary step was taken in which a state-space model with “resident” and “migratory” states was fit to the archival tag positions using distance travelled between daily positions as input data. Then, in the habitat preference model, only data where fish were in a resident state were included, since environmental conditions may not be as influential to fish location when the fish is migrating. We chose not to include this preliminary step in this project because it makes little difference to the habitat preference model in the GAB, where fish are in a resident state the majority of the time. Basson et al. (2012) also considered the option of smoothing the preference curve or surface to get rid of noise where there is little data (i.e. by fitting a GAM to the empirical preference data as a function of the environmental covariates). While there are advantages to smoothing the preference output, there are also disadvantages, such as sometimes the smoothing masks what might be real preferences. We preferred to use the empirical preferences in this project.

Seasonal forecasting model

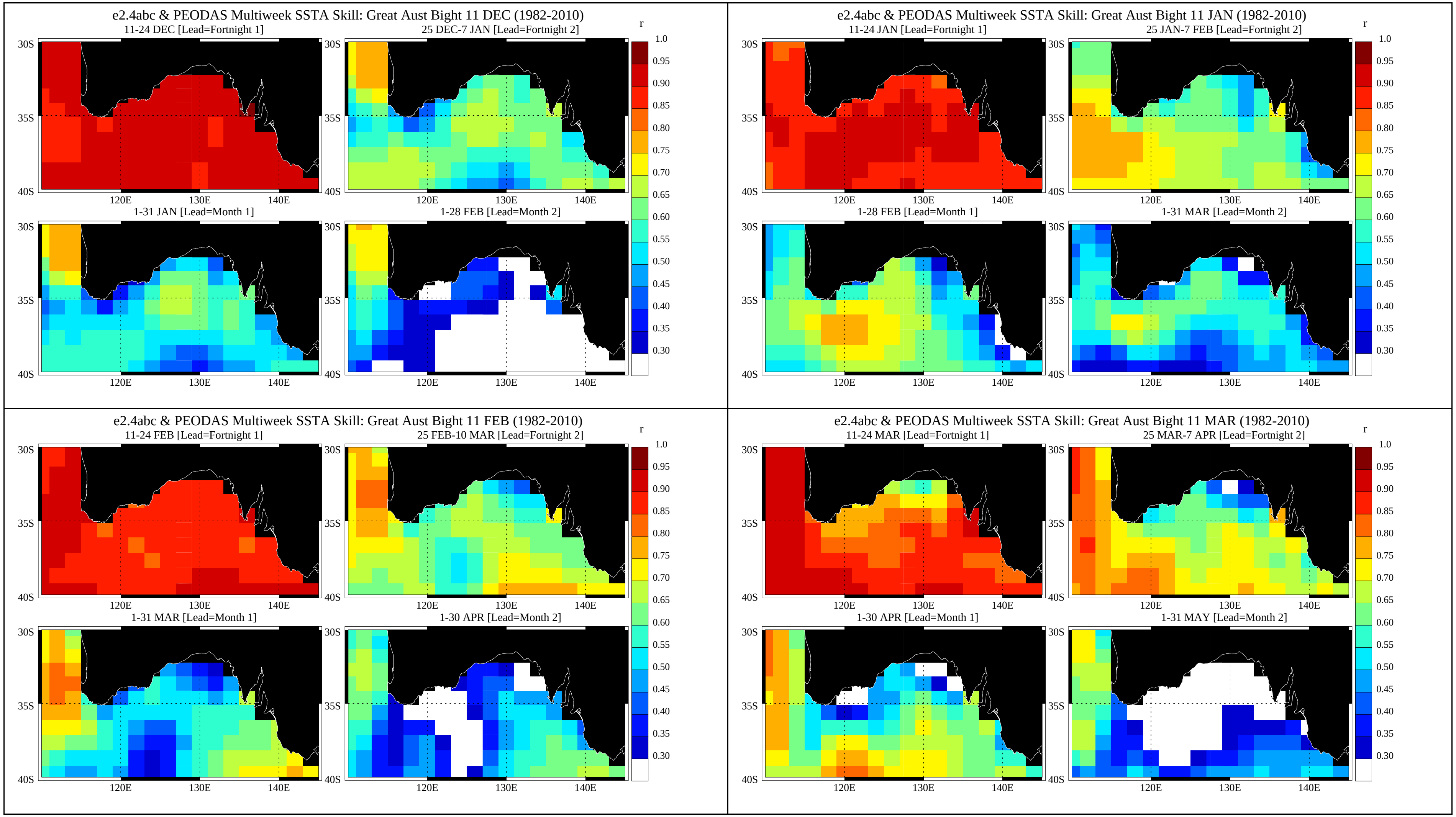
POAMA SSTA forecast skill, as measured by Pearson’s correlation coefficient (r), for December, January, February and March for 1st, 11th and 21st start dates during the period 1982-2010 for the GAB is shown in Figure 11. When r equals 0, there is no correlation between the forecasted SST anomaly and the observed SST anomaly; when r equals 1, there is a perfect positive correlation. In general, forecast skill is high ($r > 0.8$) for the first fortnight for all start dates for all months and decreases with lead-time. Skill tends to be higher in the west of the domain than in the east. As start dates within each start month increase from the 1st to the 21st, skill improves for the monthly forecasts m1 and m2 across all start months December-March. This makes sense as the time elapsed between the model start date and the forecast date decreases, i.e., for a model start date of 1st January, the February m1 forecast has an effective lead-time of 31 days, whereas for a model start date of 21st January, the February m1 forecast has an effective lead-time of 10 days. In most instances, skill for the m2 forecasts is not significant ($r < 0.3$), indicating that the forecast is not useful, over large areas of the GAB for all start months and dates, with the exception of forecasts starting in January (for which m2 corresponds to March forecasts).

The most recent SST forecasts available at the time of writing this report were issued on the 21st of September 2014. In terms of this project, SST in the GAB at this time of year is not particularly interesting because it is too cold to be preferred habitat for SBT. Thus, rather than showing the most recently available forecasts, we show the SST forecasts that were issued on the 1st of January for the first fishing season of this project (2013) (Figure 12). The forecasts are for the first two weeks of January (f1), the second two weeks of January (f2), February (m1) and March (m2) (Figure 12, top row). Also shown is the actual observed average SST for the same time periods for comparison (Figure 13Figure 12, bottom row). As we might expect, the forecast for March was not as good as for the shorter lead-times, with the forecast made on the 1st of January predicting cooler temperatures in the east than were actually observed.

(a) Skill of forecasts issued on the 1st of the month.



(b) Skill of forecasts issued on the 11th of the month.



(c) Skill of forecasts issued on the 21st of the month.

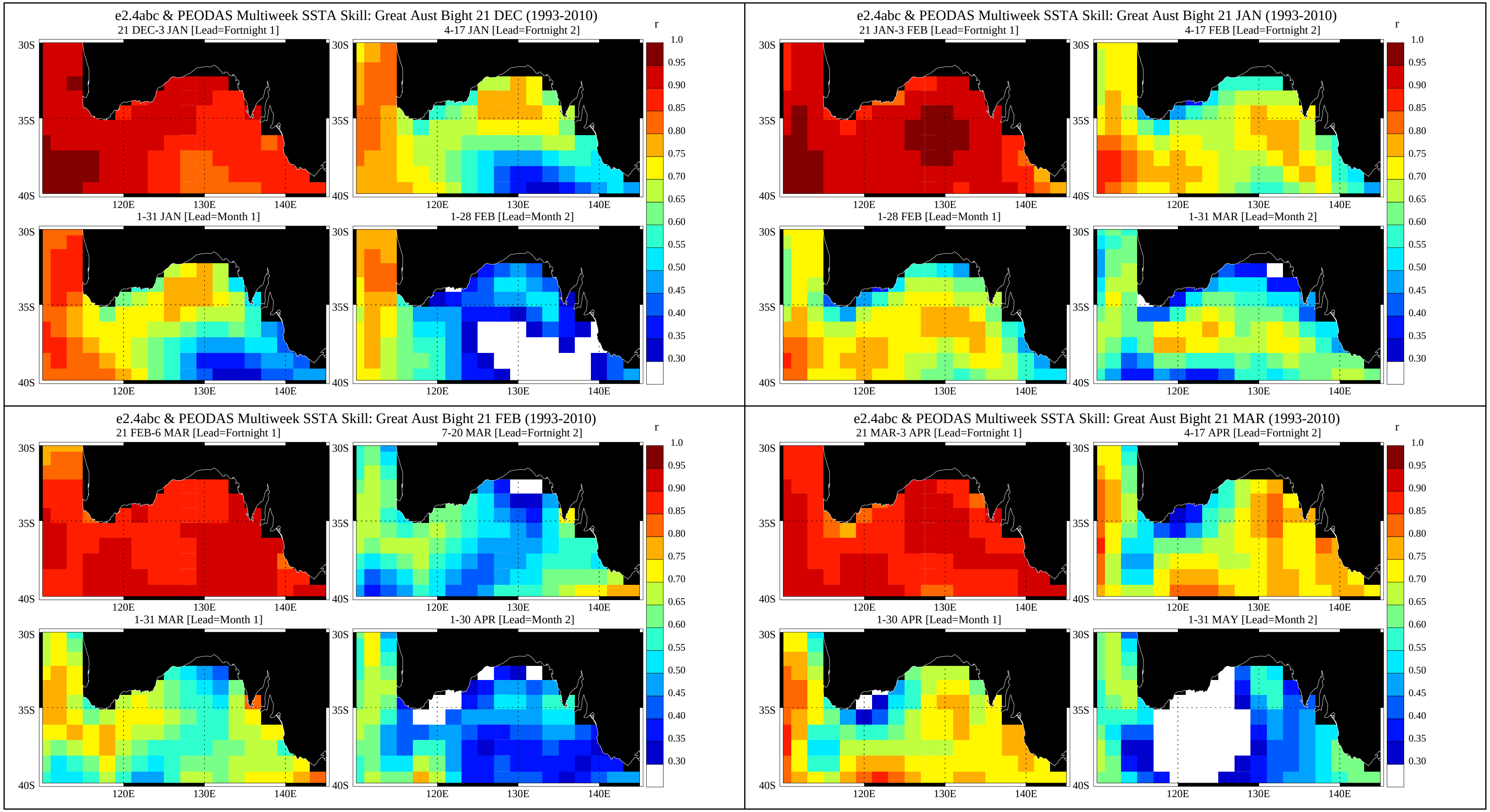


Figure 11. Skill of SST forecasts starting on (a) 1st, (b) 11th and (c) 21st of the month for December (top left panel), January (top right panel), February (bottom left panel) and March (bottom right panel) from 1982-2010 for lead-times fortnight 1 (f1; inner top left), fortnight 2 (f2; inner top right), month 1 (m1; inner bottom left) and month 2 (m2; inner bottom right). Skill is measured by Pearson's correlation coefficient (r), where r<0.3 (white) indicates poor model skill and r>0.8 (dark orange to red) indicates high model skill.

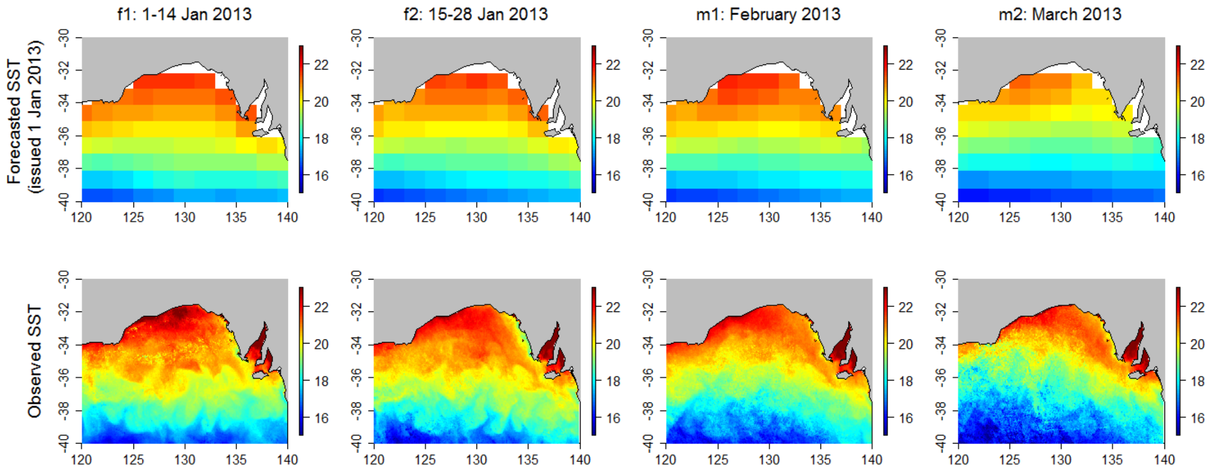


Figure 12. SST forecasts (top row) issued on the 1st of January 2013 for 1-14 January (f1), 15-28 January (f2), February (m1) and March (m2), plus observed average SST for the same time periods (bottom row).

Habitat forecasts

As noted in the previous section, the SST forecasts, and in particular the corresponding habitat preference forecasts, for the most recently issued forecasts (21 September 2014) are not of particular interest because it is too cold to be preferred habitat for SBT. Instead, we again use the SST forecasts that were issued on the 1st of January 2013 for the first two weeks of January (f1), the second two weeks of January (f2), February (m1) and March (m2) to show examples of habitat preference forecast maps corresponding to these time periods (Figure 13). Based on the skill evaluation of the SST forecast model, we would have lower confidence in the habitat preference map for March (m2).

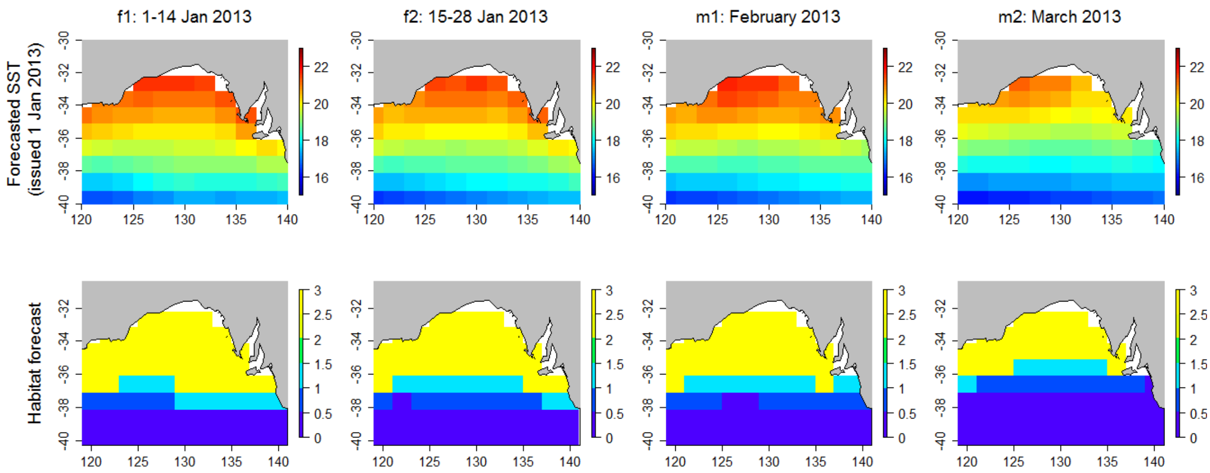


Figure 13. SST forecasts (top row) and corresponding habitat preference forecasts (bottom row) issued on the 1st of January 2013 for 1-14 January (f1), 15-28 January (f2), February (m1) and March (m2).

The habitat forecasts issued on the 1st of January 2013 (Figure 13) predicted essentially all of the GAB to be preferred habitat for SBT in January through March. This is because POAMA (correctly) forecasted SST to be above average in the 2013 season, so that even in early January, the eastern GAB was forecasted to be warm enough to be preferred habitat. In contrast, POAMA forecasts of SST issued on the 1st of January 2005 correctly predicted much cooler temperatures in the GAB for the 2005 season (Jan-Mar), particularly in January and in the eastern GAB (Figure 14, top row). Thus, much of the GAB did not fall within the preferred SST range for SBT, and this was reflected in the habitat preference forecasts (Figure 14, bottom row).

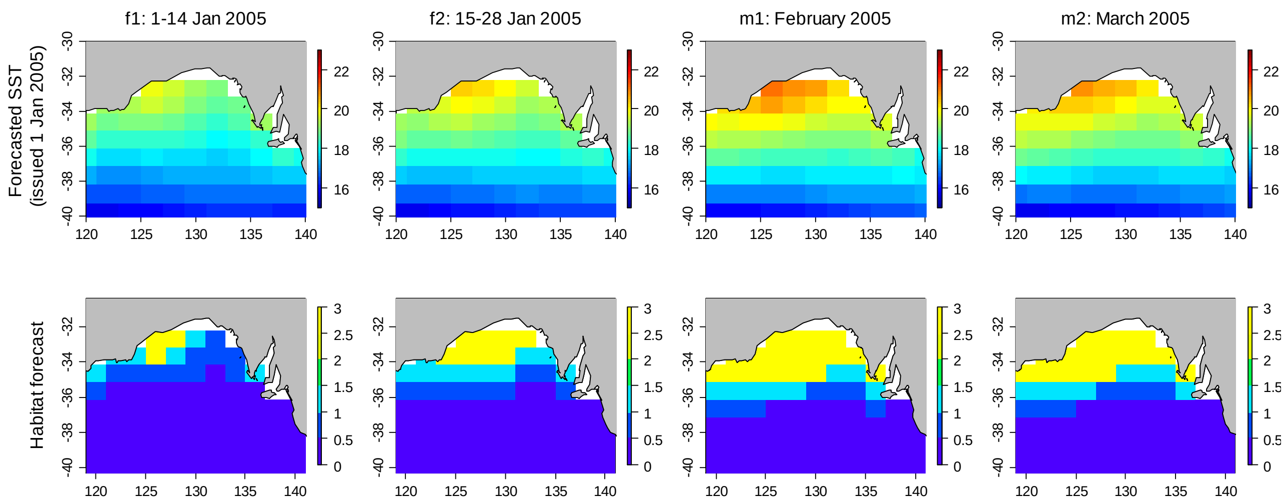


Figure 14. SST forecasts (top row) and corresponding habitat preference forecasts (bottom row) issued on the 1st of January 2005 for 1-14 January (f1), 15-28 January (f2), February (m1) and March (m2).

Delivery of results to industry

In the first year of the project, ahead of the 2013/14 fishing season, we developed a prototype website for industry that included maps of observed and forecasted SST data in the GAB, along with graphs showing the range of SST values preferred by SBT when in the GAB. The website also provided information about the skill (accuracy) of the SST forecasts produced by POAMA and about the methods used to estimate preferred SBT habitat. It did not at this early stage include maps of preferred habitat for current or forecasted environmental conditions, plus the SST forecasts were made using version 1 POAMA that only allowed for monthly (not fortnightly) forecasts. The website was, and currently remains, hosted on a CSIRO site:

www.cmar.csiro.au/gab-forecasts. A recent screen grab of the website home page is shown in Figure 15, and a schematic showing the types of information found on the tabbed pages of the website is shown in Figure 16.

The website was presented to industry members in Port Lincoln in late October 2013. At the same time, a handout was distributed describing the project and the expected outcomes (Appendix 4), as well as a general survey to elicit how decisions made by industry representatives are influenced by environmental conditions and whether seasonal forecasts would be useful to these decision-making processes (Appendix 4). The presentation succeeded in gaining the interest of industry, and provided useful feedback about the website. There has been ongoing liaison with industry throughout the project through co-investigator Kirsten Rough, a research scientist with the Australian SBT Industry Association (ASBTIA). Information from the website has been included in the weekly updates on climate systems and local oceanography that are distributed to ASBTIA members. Comments and questions received on these updates have guided modifications to the website. The website was updated throughout the first season to include the most recent observed and forecasted SST data. Regular modifications were made to the information content and layout of the website in response to ongoing feedback from industry. Examples of modifications include adding close-ups of some of the figures, including the shelf break depth contour on all maps, and including a graph of SST along the shelf break for the observed SST map (as for the forecasted maps).

At the conclusion of the first season of forecast provision (March 2014), industry decision-makers were formally surveyed to determine satisfaction with delivery mechanism, and to evaluate if the forecasts influenced their decision making. A total of six responses were received from senior decision makers in the tuna catching companies (e.g. operations managers, managing directors), and one response from a senior representative of the associated bait industry. Tuna industry participants had between 14 and 64 years of experience in this fishery. All participants had used the website at frequencies ranging from once for the season up to twice per week (mode weekly). Although the focus of the project was on delivery of seasonal environmental and habitat forecasts, information on recent observed ocean conditions was considered very useful, with the modal satisfaction score for information presented being 8/10 (minimum 8/10, maximum 10/10). This information was previously available in a range of disparate locations, but industry decision makers considered that aggregating it in a single location and consistent format was highly beneficial. The forecasts were also considered very useful, with satisfaction scores for information delivery ranging from 8/10 to 9/10. The overall delivery mechanism (information and forecasts) was rated between 8/10 and 10/10 (mode was 10/10). Of the six participants responsible for decision-making related to capture of SBT in the year 2013/14, four reported that they made a decision in response to the seasonal forecasts. The other two decision-makers had taken a wait-and-see approach, and did not use the forecasts to alter their decision-making.

Participants suggested a range of information they would like to see delivered. This was generally related to historical or real-time data, which would allow the context of the forecasts to be evaluated. Suggestions included providing maps of recent chlorophyll, wind, and salinity fields, changes to the spatial coverage of data (broad and focused coverage), and inclusion of tracking data from tagged tuna to illustrate habitat associations. A range of these suggestions were included in revising the website (such as including a map of recently observed chlorophyll), however some were outside the objectives of this project (e.g., maps of recent wind and salinity conditions are not used in the habitat preference model, nor are they forecasted variables).

A number of other revisions and additions were made to the website between the end of the first fishing season (March 2014) and the time of writing this report (September 2014). Importantly, maps were added showing estimated areas of preferred SBT habitat corresponding to recently observed and forecasted environmental conditions. Also, the SST forecasts were updated using the new multi-week version of POAMA that allows for fortnightly forecasts (f1: the next two weeks, and f2: the following two weeks). We expect industry to find these shorter-term forecasts a useful addition to the monthly forecasts. A page was also added to the website providing information about the method used to estimate positions from archival tags, along with maps of estimated tracks for a sample of recaptured fish. Furthermore, since this project was motivated in large part by observed changes in the spatial distribution of SBT through recent fishing seasons, case studies were added showing environmental conditions in the GAB during these seasons and also evaluating how well and how far in advance the forecasted SST data were able to characterize the observed data.

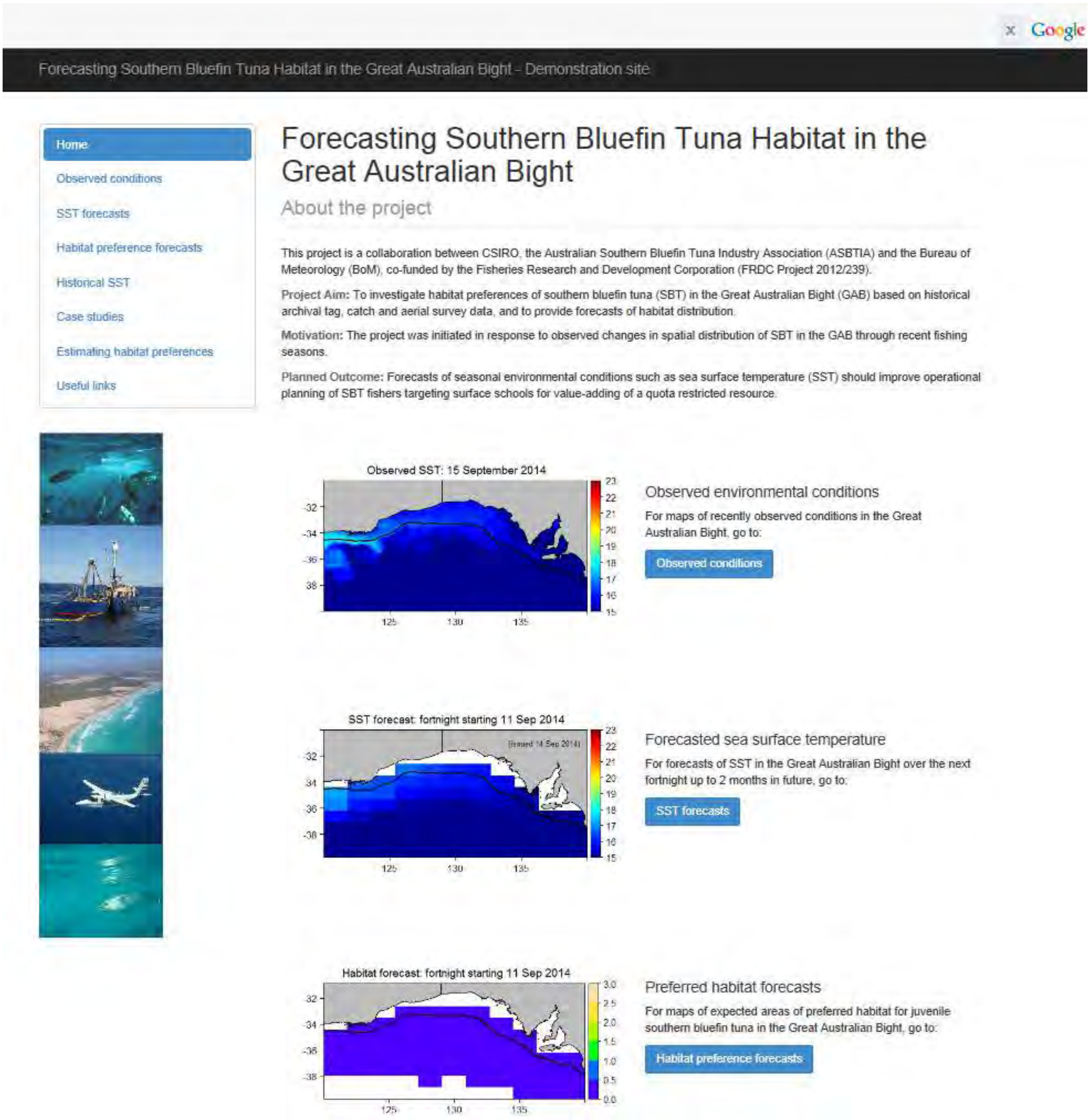


Figure 15. Screen grab of website home page.

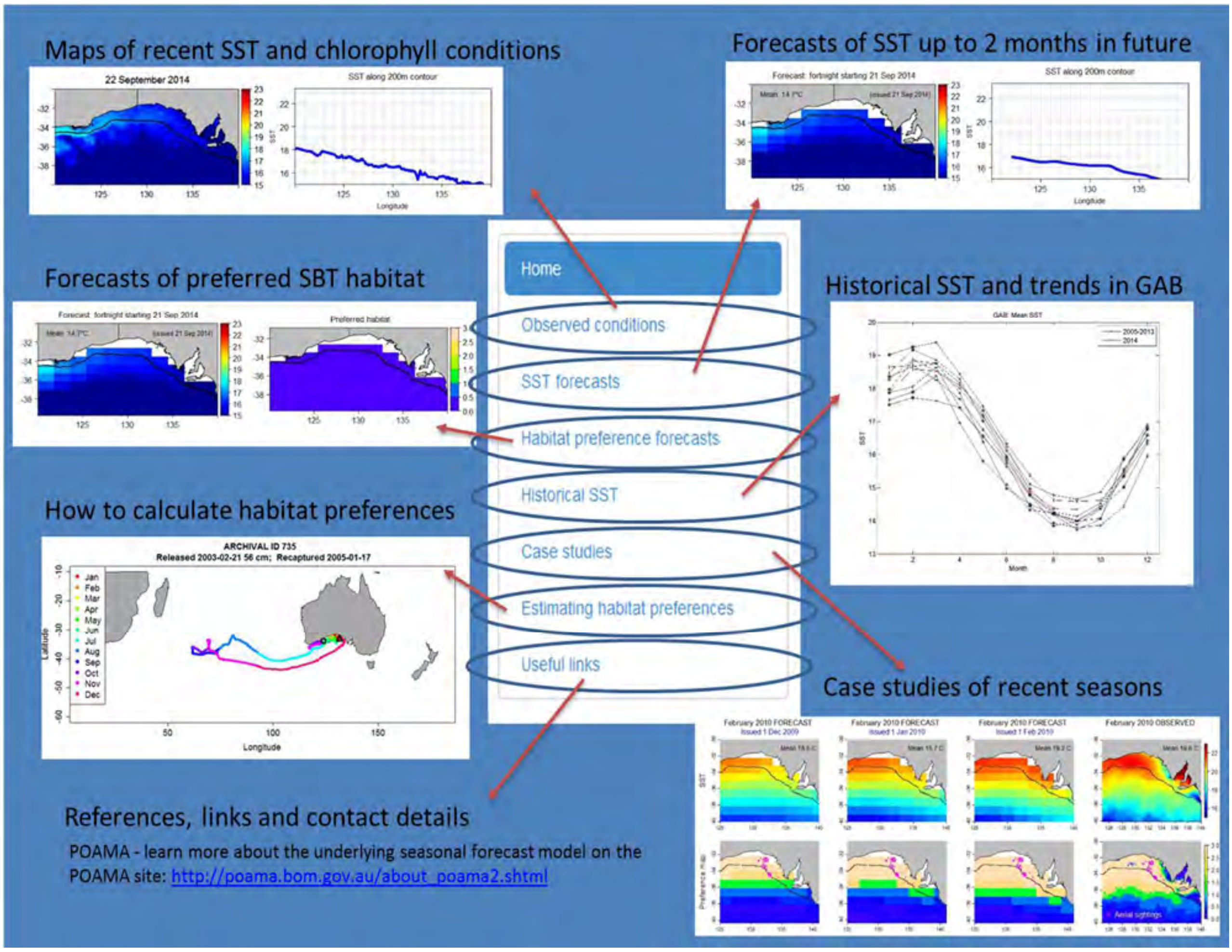


Figure 16. Schematic of website showing examples of what types of information can be found on each of the website pages.

Conclusions

This project has met all objectives on time and delivered a range of outcomes, including ones that were uncertain at the time of the proposal and which we planned to evaluate during the project. The overarching goal, to provide forecasts of SBT habitat distribution in the GAB (Objective 4), was achieved. Thus, in developing forecasts based on a habitat model, we exceeded the intermediate (and fall-back) goal (Objective 3), which was to produce forecasts of useful ocean variables (e.g. temperature). Both ocean variable and habitat forecasts are now delivered via an industry-specific website, which has been developed and refined in response to ongoing dialogue with industry representatives. The habitat model was developed and validated using historical archival tag data (Objective 1) and provided several case studies of tuna distribution in recent years that help explain how the forecasting model works. Thus, we also met the objective of delivering "nowcasts" of habitat distribution corresponding to the most recent observed environmental conditions in the GAB based on habitat preferences (Objective 2), which would have been the fall-back if the habitat forecasts were not successful or useful.

Developments in the Bureau of Meteorology's seasonal forecasting model (POAMA) during the course of the project also allowed the project team to develop finer scale forecasts (for the next two fortnights, and then subsequent months) rather than just monthly forecasts. Industry rated the real-time observations and shorter-term forecasts as particularly useful, and thus the fortnightly forecasts allow an even better short-term decision support for the SBT purse seine fishery. Analysis of historical datasets showed that the environmental and habitat forecasts in the GAB have skill out to approximately 2 months, and so provide a planning tool over this time horizon. We provided information on the skill of the forecasts, so that decision makers can judge the quality of the forecasts for any time of year. Ongoing conversations will lead to greater awareness of the strengths and limitations of forecast – they can still be wrong – but sustained use is likely to lead to positive outcomes over using "average conditions" to plan business operations.

Engagement with industry via face-to-face presentations and regular briefings by the industry co-investigator allowed rapid feedback and improvements to the web delivery and explanation of the forecasts. Thus, the project now also delivers additional environmental information that decision-makers in the fishery have requested. For example, information on present conditions (nowcasts) are seen as useful stepping stones to decision making on seasonal timescales and having multi-week forecasts (fortnightly) will further assist industry. Formal feedback has judged the project to be a success and to have met the expectations of the industry.

Overall, the SBT industry in the GAB now has a seasonal forecasting decision support tool that is automatically updated and accessible from a targeted website. A range of historical environmental information and case studies on the website provide additional context for decision making. This tool will assist fishers in making decisions that require forward planning, and places the industry in a better position to respond to change on a range of time scales. Wise use of this information should also enhance the economic efficiency of this quota-managed fishery because it will assist fishers in identifying likely SBT distribution weeks to months ahead of time, which may enable them to catch their quota more efficiently over shorter periods of time.

Implications

The most desirable outcome of this project would be improved business planning around fishing strategies by managers and industry members considering upcoming environmental conditions and potential distribution of tuna habitat. Ultimately, this could lead to improvements in profitability. As the fishery is quota managed, locating and catching fish in the shortest amount of time is preferable. While spotter planes are used to locate fish at short time-scales, longer term information can be used to decide where and when to send fishing vessels. These forecasts of projected SBT habitat in the GAB at lead-times of up to 2 months should allow operators to plan some of these fishing operations. For example, projected preferred habitat conditions far to the west may involve different fishing strategies than projected preferred habitat conditions near Port Lincoln. These future planning skills should also increase general planning around future environmental conditions.

The ‘public good’ components of this project are: a) improved understanding of SBT spatial dynamics in relation to the environment can inform/validate the aerial survey design and data interpretation, thus enhancing Australia’s commitment to international obligations through the Commission for the Conservation of Southern Bluefin Tuna (the abundance index derived from the aerial survey is an important input to the operating model and management procedure for SBT; Hillary et al. 2012), and b) success of a multi-variable forecasting model could be adopted for management of SBT by-catch in the Eastern Tuna and Billfish Fishery (i.e. the East Coast Line; Hobday et al. 2012) and more broadly across other fisheries.

At this time, the direct calculation of industry cost savings cannot be provided, but this could be a focus for follow-up work.

Recommendations

Recommendations for other steps that may be taken to further develop the results and outcomes from this project include:

- Continue to evaluate the use of the forecast system by industry participants via feedback from ASBTIA.
- Update the habitat model as environmental conditions and fish response change in the future (e.g. climate change). We suggest this is best done in 3-5 years' time, when data from the next set of archival tags from the Great Australian Bight Research Program (www.bpgabproject.com.au/go/doctype/5771/160075/Great-Australian-Bight-Research-Program) may be available.
- Improve the habitat model by including uncertainty in the positions estimates from archival tags.
- Demonstrate the approach to other fishing and aquaculture industries that could use similar systems, via publications and presentations.
- Attempt to make a direct calculation of industry cost savings as a result of improved planning around future environmental conditions.

Further development

All the project objectives were achieved. The main issues around further development are the long-term hosting of the website, as discussed in the next section.

In addition, forecasting is currently limited with respect to the environmental variables that POAMA can forecast (e.g. ocean temperature). Hence other variables that are important in explaining variation in historical distribution of SBT (e.g. chlorophyll) cannot be included in a habitat forecast. We could use statistical techniques to evaluate the co-variation pattern between data that are available (e.g. SST) and unavailable (e.g. chlorophyll) from forecast models to explore the viability of adjusting future habitat forecasts using that pattern (e.g. PCA, spatial GAMs, or other statistical techniques). This research could improve the accuracy of forecasts, and increase the lead-time at which forecasts can be made.

These forecasts are suitable for offshore fishing and marine management applications, but additional near-shore applications (e.g. oyster aquaculture) are currently limited. The project team is developing extrapolation and downscaling applications that will increase the resolution offshore, and increase coverage for near-shore applications.

Extension and Adoption

The key output of the project is a website for the SBT industry. Throughout the project, the information content and layout of the website was communicated to industry members and managers through a number of handouts and presentations (see ‘Contact with beneficiaries’ below). The website is already being used by decision makers in the SBT industry. It provides (i) environmental forecasts of variables found to influence SBT distribution in the GAB, and, (ii) forecasts of preferred SBT habitat in the GAB. The project’s official end date is 3 December 2014, at which point the project team will deliver a ‘final’ version of the website; however, we propose to make any further minor changes to the site up until 31 March 2015 based on feedback from the 2014/15 fishing season. Options for ongoing accessibility and maintenance of website after the conclusion of the project are outlined below.

<u>The major adoption challenge is to ensure long-term industry accessibility to forecasting information via the website</u>. The website is currently hosted by CSIRO, but after all changes are completed, it could be hosted on the BoM or ASBTIA site for ongoing years. An advantage of continued hosting by CSIRO is that updating procedures have already been developed such that forecasts available from the website can be updated automatically for use in subsequent seasons at no cost. <u>Four additional issues exist regarding ongoing maintenance of this (and any) website:</u>

1. There may be situations where small things go wrong, such as changes to the location or format of the files being downloaded for the automatic updates. If the problem is minor, it should be simple to fix (by CSIRO, BOM or ASBTIA staff) without the need for additional funds. In terms of minor updates to the website (necessary or requested), and depending on where the website is hosted, ASBTIA could make these updates. For example, maps of historic data, or links to other useful sites, could be kept up to date by ASBTIA (e.g. Kirsten Rough). There may be transfer costs as part of transferring the website to a new host, if this option is selected.
2. Changes to seasonal forecasting model. The forecasts are based on a seasonal forecasting model from the BOM (POAMA v2). This model is updated from time to time, and is also scheduled for replacement as part of the ACCESS program in the next 5 years (to provide Australia with new

weather, seasonal, and climate scale forecasting capability). This may require a change to the computer codes that generate the forecasts, checking of the performance of the new forecast model (it should get better!) and updating process to the website. Updating the forecast model to accommodate these changes is not expected to be a major or costly challenge.

3. Tagging data supporting the habitat preferences. The forecast model is based on habitat preferences derived from biological data collected on SBT during 1998-2009 from archival tags. These habitat preferences can continue to be used into the future, but *cannot* be updated automatically to include tag data from future years. Forecasts will continue to be delivered based on these habitat preferences at no cost, and this should be sufficient for the next few years, but we recommend updates should occur in the future (see Recommendations) since SBT 'preferences' may change (particularly given the increasing trend in temperature in the GAB over recent years). New archival tag data for juvenile SBT is expected to come available in 3-5 years' time (see Recommendations), in which case CSIRO could undertake an update of the habitat preference analysis with this new biological data; however, costing and funding of such an exercise would need to be determined.
4. Loss of primary data. More significant problems (such as loss of satellite data coverage, loss of internet services, etc.) could disrupt forecast delivery. Such scenarios are beyond the control of the project team and could lead to cessation of forecast capability.

<u>Contact with beneficiaries:</u>

- 29 Oct 2013: Presentation to industry, Alistair Hobday, Port Lincoln. Delivery of project handout, distribution of project survey, and demonstration of demo website. Received lots of interest and positive feedback about website, also suggestions of other information that might be useful for website if possible.
- 22 Nov 2013: Industry Executive Meeting. Kirsten Rough presented update on project and demo website. Received very positive feedback.
- 27 Nov 2013: ASBTIA-FRDC Industry Workshop and SRC meetings: Kirsten Rough presented update on project.

- Regular basis throughout project: SST and habitat “nowcasts” and forecasts from the website were included in the weekly climate and oceanographic summaries issued to ASBTIA industry members by Kirsten Rough. Received positive feedback and suggestions to further improve delivery of information.
- 27 Nov 2014. Presentation to Industry, Alistair Hobday, Port Lincoln. Demonstration of revised website and opportunity for final industry feedback/suggestions.

Project coverage

There were no media, industry or government articles on this project to report.

Project materials developed

Project-specific materials

1. Website for use by industry showing forecasts of environmental variables and preferred habitat of SBT in the GAB (http://www.cmar.csiro.au/gab-forecasts/index.html)

2. Handout for industry outlining the project and expected outcomes (Appendix 4)

3. Questionnaire distributed to industry at start of project regarding decision making and expected utility of seasonal forecasts (Appendix 4)

4. Survey distributed to industry near end of project to get feedback about actual utility of seasonal forecasts and website (Appendix 4)

Conference presentations and posters

5. Ocean Sciences, Hawaii, Feb 2014: C. Spillman presented a talk entitled “Dynamical seasonal forecasting to support the management of wild Southern Bluefin Tuna fisheries in Australia”

6. International Statistical Ecology Conference, France, July 2014: P. Eveson presented a talk entitled “Preferred habitat of juvenile Southern Bluefin Tuna in the Great Australian Bight”

7. Australian Marine Science Association (AMSA), Canberra, July 2014: C. Spillman (on behalf of A. Hobday) presented a talk entitled “New forecasting tools for proactive management of Australian Southern Bluefin Tuna Fisheries”

8. AMSA, Canberra, July 2014: C. Spillman presented a talk entitled “Seasonal forecasting for decision support in marine fisheries and aquaculture”

9. Biologging, France, September 2014: J. Hartog presented a poster entitled “Preferred habitat of Southern Bluefin Tuna around Australia: Management applications from biologging technology”

Publications – peer reviewed

10. Hobday, A. J., C. M. Spillman, J. R. Hartog and J. P. Eveson (in press). Seasonal forecasting for decision support in marine fisheries and aquaculture. Fisheries Oceanography.

11. Eveson, J. P. , A. J. Hobday, C. M. Spillman, K. Rough, J. R. Hartog. (in preparation) Seasonal forecasting of tuna habitat in the Great Australia Bight.

Appendix 1: List of researchers and project staff

- Paige Eveson (PI), CSIRO
- Alistair Hobday, CSIRO
- Jason Hartog, CSIRO
- Marinelle Basson, CSIRO
- Toby Patterson, CSIRO
- Claire Spillman, Bureau of Meteorology (BoM)
- Kirsten Rough, Australian Southern Bluefin Tuna Industry Association (ASBTIA)

Appendix 2: Intellectual Property

The archival tag data used in this project were collected under other projects and the IP remains with those projects. Some of the methods applied in this project relating to geolocation from archival tag data and estimating habitat preferences were also developed under external project funding arrangements. The IP for these methods remains with the original developers and projects. Environmental data from remote-sensed products used in the analyses is publicly available and so should not be considered IP from this project.

Appendix 3: References

Basson, M., Hobday, A.J., Eveson, J.P., Patterson, T.A. 2012. Spatial interactions among juvenile Southern Bluefin Tuna at the global scale: A large scale archival tag experiment. FRDC Report 2003/002.

Beggs, H. 2007. A high-resolution blended sea surface temperature analysis over the Australian region, BMRC Research Report, RR130, Bureau of Meteorology Australia. 43 pp.

Hillary, R., Preece, A., Davies, C. 2012. Developing a management procedure based recovery plan for southern bluefin tuna. Final report to the Australian Fisheries Research and Development Corporation. Project No. 2011/034. http://www.frdc.com.au/research/Documents/Final_reports/2011-034-DLD.pdf

Hobday, A.J., Hartog, J., Spillman, C., Alves, O. 2011 Seasonal forecasting of tuna habitat for dynamic spatial management. Canadian Journal of Fisheries and Aquatic Sciences 68, 898–911.

Hobday, A.J., Hartog, J., Spillman, C., Hudson, D. July 2012. Seasonal forecasting to improve resilience of prawn farms to future climate events. (Draft Final report to Rural Resilience Industry Grants Program; not yet publicly available).

Hobday, A.J., Spillman, C.M., Eveson, J.P., Hartog, J.R. 2014. Seasonal forecasting for decision support in marine fisheries and aquaculture. Fisheries Oceanography. doi:10.1111/fog.12083.

Hudson, D., Alves, O., Hendon, H.H., Wang, G. 2011: The impact of atmospheric initialisation on seasonal prediction of tropical Pacific SST. Climate Dynamics. 36:1155-1171.

Pedersen, M.W., Patterson, T.A., Thygesen, U.H., Madsen, H. 2011. Estimating animal behavior and residency from movement data. Oikos, 120: 1281-1290. doi: 10.1111/j.1600-0706.2011.19044.x

Spillman, C. M., Alves, O. 2009. Dynamical seasonal prediction of summer sea surface temperatures in the Great Barrier Reef. Coral Reefs 28: 197-206.

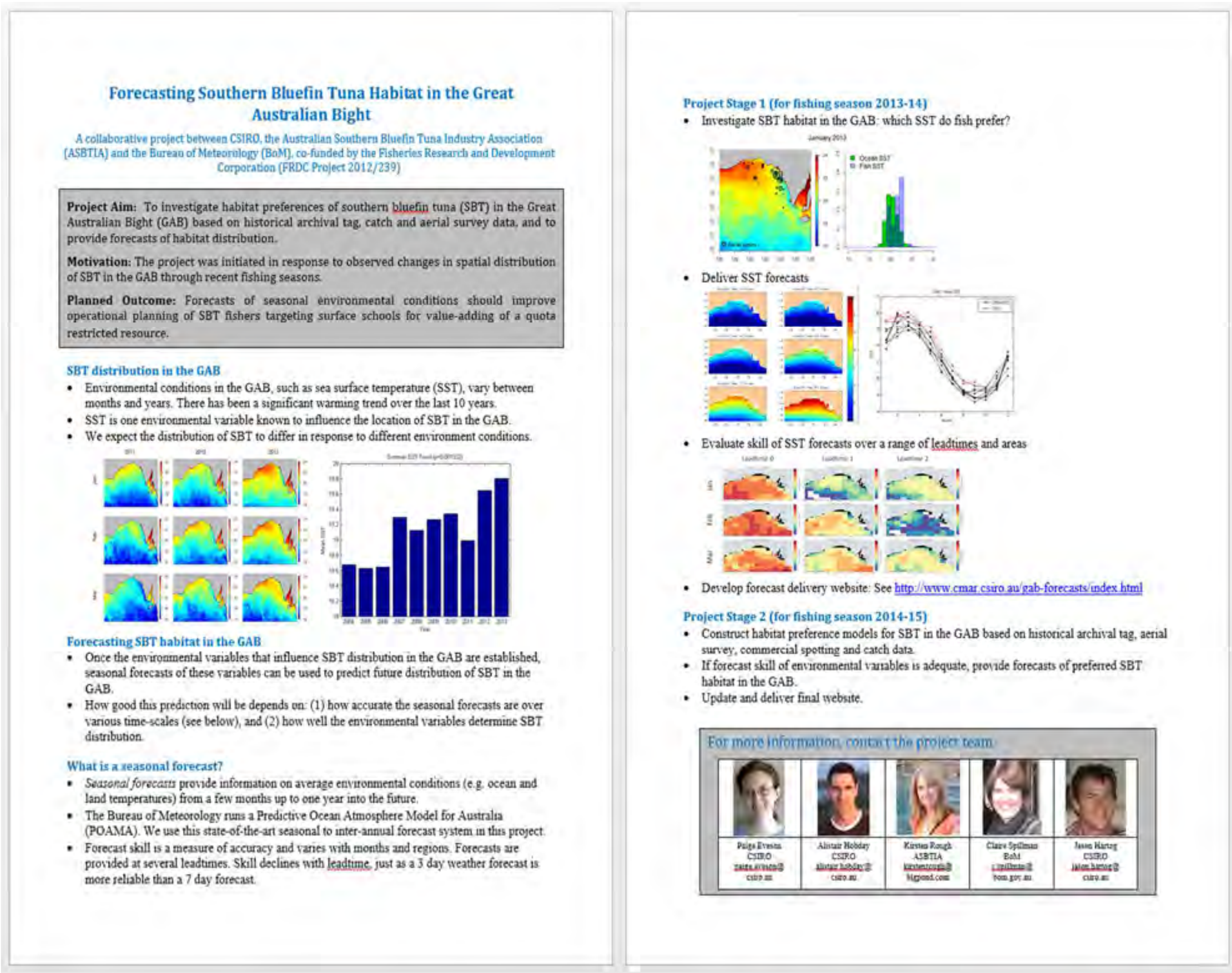
Stockdale, T.N. 1997. Coupled ocean–atmosphere forecasts in the presence of climate drift. Mon. Weather Rev. 125(5): 809–818. doi:10.1175/1520-0493(1997)125<0809:COAFIT>2.0.CO;2.

Yin, Y., Alves, O., Oke, P.R. 2011. An ensemble ocean data assimilation system for seasonal prediction. Monthly Weather Review 139:786-808.

Appendix 4: Project materials

Handout for industry

The following handout outlining the project and expected outcomes was prepared and distributed to industry in October 2013.



Forecasting Southern Bluefin Tuna Habitat in the Great Australian Bight

A collaborative project between CSIRO, the Australian Southern Bluefin Tuna Industry Association (ASBTIA) and the Bureau of Meteorology (BoM), co-funded by the Fisheries Research and Development Corporation (FRDC Project 2012/239)

Project Aim: To investigate habitat preferences of southern bluefin tuna (SBT) in the Great Australian Bight (GAB) based on historical archival tag, catch and aerial survey data, and to provide forecasts of habitat distribution.

Motivation: The project was initiated in response to observed changes in spatial distribution of SBT in the GAB through recent fishing seasons.

Planned Outcome: Forecasts of seasonal environmental conditions should improve operational planning of SBT fishers targeting surface schools for value-adding of a quota restricted resource.

SBT distribution in the GAB

- Environmental conditions in the GAB, such as sea surface temperature (SST), vary between months and years. There has been a significant warming trend over the last 10 years.
- SST is one environmental variable known to influence the location of SBT in the GAB.
- We expect the distribution of SBT to differ in response to different environment conditions.

Forecasting SBT habitat in the GAB

- Once the environmental variables that influence SBT distribution in the GAB are established, seasonal forecasts of these variables can be used to predict future distribution of SBT in the GAB.
- How good this prediction will be depends on: (1) how accurate the seasonal forecasts are over various time-scales (see below), and (2) how well the environmental variables determine SBT distribution.

What is a seasonal forecast?

- *Seasonal forecasts* provide information on average environmental conditions (e.g. ocean and land temperatures) from a few months up to one year into the future.
- The Bureau of Meteorology runs a Predictive Ocean Atmosphere Model for Australia (POAMA). We use this state-of-the-art seasonal to inter-annual forecast system in this project.
- Forecast skill is a measure of accuracy and varies with months and regions. Forecasts are provided at several leadtimes. Skill declines with leadtime, just as a 3 day weather forecast is more reliable than a 7 day forecast.

Project Stage 1 (for fishing season 2013-14)

- Investigate SBT habitat in the GAB: which SST do fish prefer?
- Deliver SST forecasts
- Evaluate skill of SST forecasts over a range of leadtimes and areas
- Develop forecast delivery website: See http://www.cmar.csiro.au/gab-forecasts/index.html

Project Stage 2 (for fishing season 2014-15)

- Construct habitat preference models for SBT in the GAB based on historical archival tag, aerial survey, commercial spotting and catch data.
- If forecast skill of environmental variables is adequate, provide forecasts of preferred SBT habitat in the GAB.
- Update and deliver final website.

For more information, contact the project team

Paige Eveson CSIRO paige.eveson@ csiro.au	Alistair Hobday CSIRO alistair.hobday@ csiro.au	Kirsten Rough ASBTIA kirstenrough@ bigpond.com	Claire Spillman BoM c.spillman@ bom.gov.au	Jason Hartog CSIRO jason.hartog@ csiro.au

Start-of-project questionnaire

The following questionnaire was distributed to industry at the start of the project regarding their decision making processes and their expected utility of seasonal forecasts.

SBT Decision making and seasonal forecasting

Farm: ___________________________________ Date: ____________________

Contact: _________________________________

Decision	Lead time	Climate influence	Forecasting helpful?
Quota			
Utilise SFR for: Fishing (direct to market) Farming (value add) Combination			
Lease out / lease in			
Fishing			
Date Start			

Farm Stocking (staggered?)			
Tow Gear preparation			
Vessel preparation			
Staff (vessels/onshore operations/office)			
Aerial support (staff/planes/contract)			
Processing factory preparation (staff/contract)			
Freight to market (airspace/freezer storage/shipping)			
Farming			
Lease site size & position			
Farm gear preparation			
Stocking date (first)			
Stocking (staggered?)			
Feed: order			
Feed: type (change in mix?)			
Feed: catch/storage			

Feed: medication (vets/production/storage)			
Marketing (approach buyers/inspections)			
Harvesting			
Freight to market (airspace/freezer storage/shipping)			
Maintenance			
Fuel (vessels/trucks)			
Ordering equipment			
Repairing vessels/equipment			
Cleaning infrastructure (nets/collars/anchors/ropes)			
Pontoon setting up / deployment			
Staffing levels			

Follow-up survey

The following survey was distributed to industry at the end of the first fishing season to get feedback about the actual utility of the website and the environmental and SBT habitat forecasts provided.

SBT industry survey to improve GAB forecast delivery

Version February 6, 2014

In order to assess current use of the forecast system and website, the project team would appreciate your answers to the following short questionnaire.

1. How long have you been involved in the SBT industry?
2. What is your current role in the SBT industry?
3. Have you looked at the SBT seasonal forecast website? Y/N (please circle)
    a. If yes, did you check it: weekly, monthly, once a season (please circle best answer)
4. The website displays current SST images – please rate the value 1-10 (low:high) ____
5. The website displays seasonal SST forecasts – please rate the value 1-10 (low:high) ____
6. Did information from the website assist you with making any decisions this year? Y/N
    a. If yes, which of the following best describes your use (please tick best answer)
        - ☐ I used the information to make an immediate decision regarding activities that could commence now.
        - ☐ I used the information to make a decision regarding activities weeks to months ahead
        - ☐ Other ___________________________
    b. If no, which of the following best describes your situation (please tick best answer)
        - ☐ I watched for any significant changes, but did not make any decisions
        - ☐ I don't think the information is useful to me in my role
        - ☐ Other ___________________________
7. What is your overall satisfaction with the information on the website – please rate 1-10 (low:high) ____
8. Are there any improvements that you would like to see? Please specify.

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