A National Reference Station infrastructure for Australia – using telemetry and central processing to report multi-disciplinary data streams for monitoring marine ecosystem response to climate change

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Abstract- **As part of a broader Integrated Marine Observing System (IMOS), the marine community in Australia is developing a National Reference Station (NRS) network to monitor coastal processes. IMOS is an Australian Government initiative established under the National Collaborative Research Infrastructure Strategy (NCRIS). The aim of NCRIS is to provide researchers with access to the infrastructure and networks to build automated and ongoing in situ observing systems necessary to undertake world-class research. The NRS network fulfils this role as part of the Australian National Mooring Network, which is one of eleven IMOS facilities. The nine stations around Australia continue and expand the three existing sites where monthly water quality data have been collected since the 1940s. The overall aim of the NRS network is to provide the data to examine interactions between major coastal boundary currents and continental shelf ecosystems, especially in the context of climate change. To do this each NRS will provide long-term data series of physical and chemical parameters alongside community composition and primary (phytoplankton) and secondary (zooplankton) biological production and diversity. This will be achieved using a combination of *in situ* measurements (moored sensors) and monthly visits to collect samples for laboratory analysis. The NRS will provide critical baseline data to examine the impact of human stresses (such as climate change and eutrophication) on Australian marine ecosystems.**

I. INTRODUCTION

The Integrated Marine Observing System (IMOS) is a nation-wide and collaborative program to observe the oceans around Australia. IMOS will provide data to support research on many critical marine issues such as climate change and sustainability of ecosystems. Recently established as part of the National Collaborative Research Infrastructure Strategy (NCRIS), the 27 IMOS partners comprise most of the Australian universities and agencies with capability in ocean and marine research. Similar to other Integrated Ocean Observing System (IOOS) throughout the world [1], IMOS facilities are mandated to provide automated and ongoing *in situ* observations in near real time. This is to be achieved by delivering data online with open-access to both individuals and institutions.

The Australian National Mooring Network is one of eleven IMOS facilities. The NRS network will consist of nine sites located in shallow depths (< 100m) on the Australian continental shelf. The overall aim of the NRS network is to provide the data to examine interactions between major coastal boundary currents with continental shelf ecosystems. The usefulness of these types of long-term monitoring projects, which fell out of favour with funding agencies in the late 1980s [2], have recently been championed by scientists interested in climate change [3,4].

The nine stations will build on three existing sites where monthly water quality data have been collected since the 1940s (Fig. 1). The three established stations, off Sydney, Rottnest Island and Maria Island, provide the only long-term data sets of physical (temperature, salinity) and chemical (nitrate, nitrite, phosphate and silicate) properties of the water column around Australia. Prior to IMOS, the stations had no permanent moorings, simply being waypoints where water samples were taken. The inclusion of moored

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instrumentation and monthly biological sampling at each NRS is a significant upgrade to the three historical sites. The addition of six new sites now provides a sparse but nationally cohesive monitoring network. Investment in moored instrumentation will allow fine temporal observations of short-term physics and chemistry and provide the context to interpret the monthly biological (plankton) sampling.

As it is most efficient if data sets are examined in concert [2] each NRS is a multidisciplinary, long-term, monitoring sites, where data are collected for oceanographic, meteorological, hydro-chemical and biological phenomena. *In situ* and monthly physical sampling will allow wide-scale validation of sea surface temperature and phytoplankton biomass to provide a national set of calibration sites for remotely-sensed chlorophyll and permit more intense process studies, located near the NRS, to be viewed in a broader (time and space) context. Expanded types, intensities and improved accuracy of the data collected will result in an increased understanding of changes in coastal water properties and how it interacts with marine biological productivity and diversity. Ultimately, the NRS will provide a baseline to assess the impact of natural and anthropogenic changes to the marine environment at a synoptic scale, to help policy makers ensure the sustainability of Australian coastal ecosystems and related fisheries.

A. Australian Coastal Boundary Currents

The circulation patterns around Australia's ~36 000 km of coastline are complex and provide a challenging environment to install permanent moorings. Strong boundary currents flow pole ward along both the east and west coasts transporting heat and tropical species to more southern waters. The East Australian Current (EAC), which originates in the southern Great Barrier Reef (GBR) reaches speeds of up to 2 ms^{-1} off the north coast of New South Wales (NSW) through most of the water column [5,6]. Downstream (south) of the EAC separation zone (~31ºS) the subsequent eddy field drives temperature variability along the coast and influences nutrient upwelling and subsequent algal blooms [7]. A dynamic coastal boundary current also runs southward along Western Australia (WA); the Leeuwin current transports warm water pole ward at speeds of up to 1-1.5 ms^{-1} [5] and eddies are regularly shed off the coast of southern WA. Across northern Australia, tidal ranges are large (up to 7 m off Darwin) which result in tidal currents of 2 ms^{-1} in Darwin Harbour (Williams pers comm.). The tropical environment is made more challenging by the sporadic occurrence of destructive cyclones.

Inside GBR lagoon, which extends the length of the Queensland (QLD) coast, the Hiri current flows northward, north of 14^{o}S, while the southward flowing EAC develops south of this point. The shallow waters (40-60 m) of the GBR lagoon are generally protected from oceanic swells, although tidal currents can be strong and again tropical cyclones pose a risk [8]. The southern Australian coastline has an unusual 'northern boundary current' [9], which reverses seasonally and can speeds of up to 0.4 ms^{-1}, eastward in winter and westward in summer.

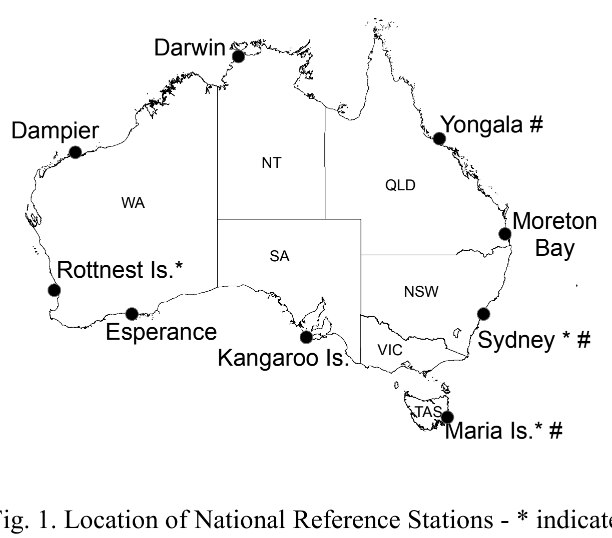

Fig. 1. Location of National Reference Stations - * indicates long term hydrographic stations
# indicates NRS mooring has been deployed.

Finally, the east coast of Tasmania is influenced by the EAC extension and its eddies, while colder currents flow along the west coast. These contrasting environments dictate that no single mooring design is suitable for all regions.

B. Response to Climate Change

Worldwide there is evidence that ocean conditions are changing. Around Australia it has been found that the Tasman Sea has the world's fastest increase in water temperature of any regional sea [10], and there is a similar warming trend off WA [11]. Furthermore the long-term hydrographic time series from the Maria Island NRS shows a significant warming trend over the last 50 years, and a trend in salinity consistent with pole ward extension of the EAC since 1944. Change per decade at Maria Island have been equivalent to $+0.22^{o}C$, and +0.03 psu, $+0.34*10^{-8}$ Nm^{-2}, and +2.0 Sv for temperature, salinity, wind stress curl and transport, respectively [12].

These changes in oceanography are now influencing both marine ecology and fisheries. For instance the long-spined urchin *Centrostephanus rodgersii*, which is normally an inhabitant of NSW (Fig. 1), has recently colonised the east coast of Tasmania. The initial incursion of *C. rodgersii* was probably via larvae transported from NSW [13] as the EAC has increased in intensity over the past 4-5 decades. In Tasmanian waters the "urchin barrens" formed by *C. rodgersii* replace the normal algal community. This, in turn negatively impacts the abundance of high value commercial species dependent on algae, such as abalone (*Haliotis rubra*) and rock lobster (*Jasus edwardsii*) [13].

C. Benefits of Long Term Observations

Only through long term and systematic sampling can annual and inter annual variability be separated from long-term trends. One of the few ways that pronounced and prolonged climate-linked changes in biological systems, such as 'regime shifts' in plankton communities [4], can be observed is with monitoring programs that develop time series data. Greater sampling effort also allows for better understanding of phenology, or seasonality, of plankton life cycles. Changes in phenology have been related to ecosystem-level change in Northern hemisphere seas and are thought to be due to climate change [4]. One of the interesting aspects of the NRS network is its combination of physical oceanography and natural sciences, observing not only physical change but also its impacts on the biology.

II. NRS RESEARCH OBJECTIVES

The NRS network, related existing and proposed IMOS infrastructure and satellite imagery when combined with ocean reanalysis models will assist in "*the generation of ocean charts for marine users similar to weather forecast charts available to the rest of the community - Dr Andreas Schiller*". The NRS thus has three main objectives:

1. *Monitor Boundary Currents* – The NRS will provide a sparse but consistent dataset observing conditions across Australia boundary currents into which local studies can be placed with increase confidence and remote sensing calibrated.
2. *Observe marine biodiversity* –Phytoplankton and zooplankton data will be used to describe the species present, their abundance, and seasonal cycles.
3. *Interpret climate variability as a window on ecological change* – Plankton population dynamics is intimately linked to its physical and chemical environment. An understanding of this link between ocean physics and plankton dynamics, particularly how populations change seasonally, can provide a window into how climate change may influence coastal ecology.

A. Capacity building

The NRS is designed to build capacity within the Australian marine scientific community by expanding the number of existing marine data streams in terms of design, geography, type, intensity of sampling and reporting of data. Unlike other maritime nations Australia is starting from a base with little existing permanent oceanographic infrastructure that telemeters data. The establishment of the NRS network does, however, give us the benefit of providing an integrated national context to work from. This paper represents an early step in this process, by reporting on the drivers and scope of the project, and the process of building capacity to move from concept to a reality.

A major challenge to developing the infrastructure are the high current velocities off the southeast and west coasts and the large seas and swell conditions that are encountered with tropical cyclones in the north and with intense storms in the southern regions. Other environmental challenges include fast rates of bio-fouling (including calcification), and mooring damage from fish bites, fish hooks and boat strike. Finally, and probably the largest challenge, is Australia's perennial problem, the tyranny of distance [14]. The logistics of developing a nation-wide NRS network in a country the size of the continental United States but with a population of only 21 million are challenging.

B. NRS Design Principles

The NRS has five major design principles:

1. Multi-disciplinary and integrated data collection
2. Modular: core high frequency data streams flow from WQMs, monthly data from discrete water samples and zooplankton tows with potential for future additional systems
3. National and regionally-scaled logistics: the mooring design is such that deployment from day boats will be possible while, monthly water samples will be transported to individual labs for centralised analytical processing
4. Telemetry of data from some NRS to the IMOS website
5. Data streams will be made promptly available and open access 'machine to machine'

C. Moored Instrumentation

At each coastal station, a mooring will be deployed with the new Water Quality Meter (WQM) developed by Wetlabs, which incorporates conductivity, temperature, depth, dissolved oxygen, fluorometer and turbidity sensors. While there have been successful deployments of WQMs such as the Land/Ocean Biogeochemical Observatory (LOBO) system [15], this will be the first continental-scale deployment of this new combination sensor. The WQMs are located at two depths (Table 1); while profiling moorings would have been ideal, during the design phase they were dismissed, as they are not yet operationally viable. Additional sensor packages to be incorporated into the NRS will be a motion recorder to collect wave data and an automated weather station (Vaisala WXT520). The weather station will be linked to a SeaBird SBE39, to provide a sampling regime of accurate measures of sea surface temperature to allow calibration with satellite remote sensing. Other sensors that may be incorporated into the NRS for particular sites include photosynthetic available radiation (PAR) sensors, acoustic Doppler current profilers, (ADCP), Kipp & Zonen net radiometers (CNR-1) and thermistor strings. These will provide additional information on water column stratification and velocity, available radiation, plankton abundance, sediment transport and sediment re-suspension. The moorings will log data internally and will be serviced between one and six months depending on location and maintenance needs. For real-time reporting each station will telemeter a reduced data set each hour.

The Tasmanian, Maria Island (42^{o} 35.80S, 148^{o} 14.00E) and Queensland, Yongala (19^{o} 18.508S, 147^{o} 37.105E) stations are the test bed moorings for temperate and tropical NRS respectively. The Maria Island design (Fig. 2) has two moorings; one is subsurface, with a WQM deployed both near the seabed and in the euphotic zone at 20 m, which transmit via acoustic modem to a surface telemetry float on the second mooring. The concept behind the two buoy system is to reduce the risk of losing the instrumentation in rough weather and to reduce instrument layover in strong currents. The Yongala NRS (Fig. 3) is a simpler design as it relies on a single mooring with inductive modems to the surface telemetry gear. Although tropical seas are generally calmer, this mooring can be removed if threatened by cyclones. Both mooring types telemeter data with the Maria NRS sending a reduced data set each hour via a short burst transmission from iridium modem to satellite and then as an emailed data package to CSIRO in Hobart, while the Yongala NRS will use the NextG mobile phone system. Eventually, numerous data streams will flow from sensors at each NRS (Table 1). The other NRS moorings around the country will be similar in concept to one of these two moorings, with some modifications depending on individual conditions. For example, the installation off Sydney will initially have no surface expression where currents are very strong. The first three NRS moorings (Fig. 1) were deployed earlier this year.

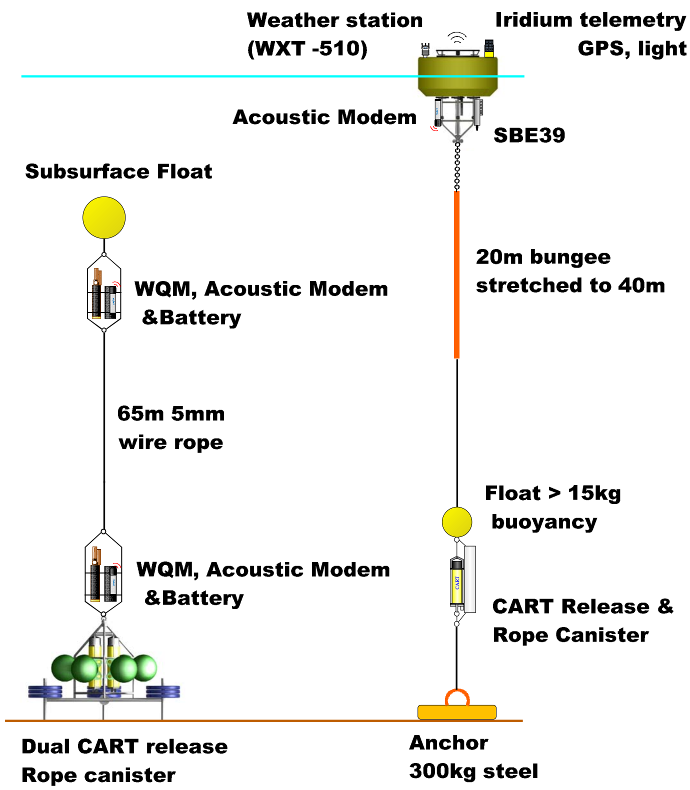

Fig. 2. Maria Island National Reference Station: temperate test bed moorings.

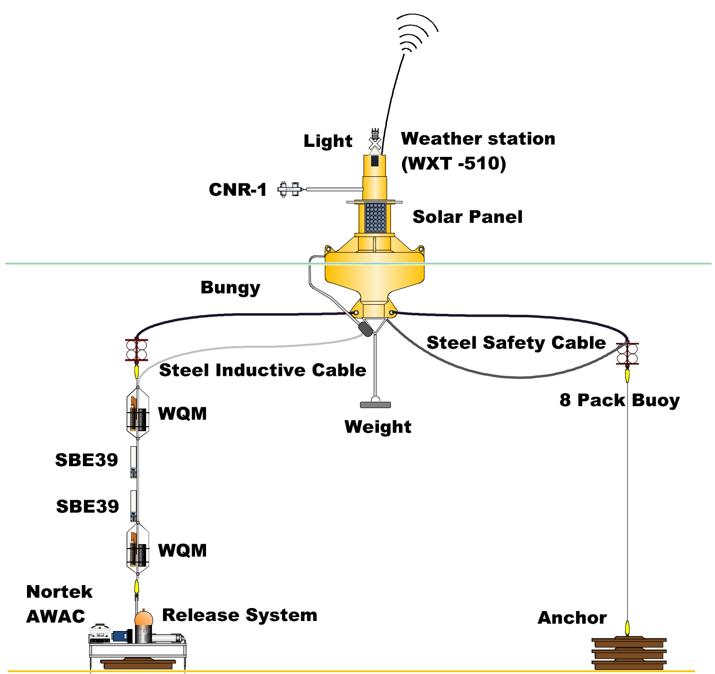

Fig. 3. Yongala National Reference Station: tropical test bed mooring

Table 1. Type, units, depth, sensors for NRS *in situ* sensors data streams (Maria Island).

Data stream type	Units	Depths	Sensor
Water Quality			
Conductivity	mmho	20m, seafloor	WQM
Temperature	°C	20m, seafloor	WQM
Pressure	dbar	20m, seafloor	WQM
Salinity	PSU	20m, seafloor	WQM
Dissolved oxygen (ml)	ml/l	20m, seafloor	WQM
Dissolved oxygen (mg)	mg/l	20m, seafloor	WQM
Oxygen saturation	%	20m, seafloor	WQM
Chlorophyll (raw)	CHL	20m, seafloor	WQM
Chlorophyll	$\mu g\ l^{-1}$	20m, seafloor	WQM
Turbidity (raw)	units	20m, seafloor	WQM
Turbidity	NTU	20m, seafloor	WQM
Site	code	20m, seafloor	WQM
Time*	Mm/dd/yy*	n/a	WQM
Date*	Hh:mm:ss*	n/a	WQM
Meteorological			
Sea surface temperature	°C	Sea surface	Seabird SBE39
Barometric pressure	hPa	1 metre	WXT520 Met St.
Wind speed	ms^{-1}	1 metre	WXT520 Met St.
Wind direction	$0 - 360^o$	1 metre	WXT520 Met St.
Air temperature	°C	1 metre	WXT520 Met St.
Liquid precipitation	mm	1 metre	WXT520 Met St.
Relative Humidity	%	1 metre	WXT520 Met St.
Wave			
Significant wave height	m	1 metre	Micro strain
Wave Spectrum	m^2/Hz	1 metre	Micro strain
Engineering			
GPS WGS 84 – lat long	Dec. seconds	1 metre	Iridium
Acceleration	ms^{-1}	1 metre	Micro strain
Site	code	n/a	CR1000
Time	24:00	n/a	CR1000
Date	dd/mm/yyyy	n/a	CR1000
Battery	volts	n/a	CR1000

D. Hydrographic and Plankton Sampling

In addition to the *in situ* measurements, each site will be visited monthly to collect water and plankton samples. Samples will be taken from the top 50 m in 5 litre Niskin bottles at 0 m, 10 m, 15 m, 20 m, 30 m, 40 m and 50 m for a total of 30 litres for discrete sampling of water chemistry at each depth. The residual will be pooled to allow for a water column sample for phytoplankton (for shallower sites multiple collection will need to occur to achieve 30 litres). The 20 m samples will correspond to deployment depths of WQMs for calibration purposes, with additional samples required when WQMs are deployed below 50 m. For zooplankton sampling, drop net tows will be conducted to 100 m depth or near the bottom for shallower sites. This and additional samples taken from the boat will contribute additional monthly data streams (Table 2).

Reporting and quality control of data will be dependent on transport of samples for centralised processing at CSIRO in Hobart for hydrochemistry and phytoplankton, and CSIRO in Brisbane for zooplankton. Sensor data will be analysed automatically at each site using data management tools developed by the Australian Institute of Marine Science (AIMS) and CSIRO. The centralised IMOS data facility (eMII) will serve and broker the NRS data and provide open access data streams online for machine-to-machine discovery.

III. CONCLUSIONS

Internationally this program is unusual as it is a co-ordinated network of National Reference Stations, which has involved a broad and multidisciplinary section of the Australian marine community. This gives us the benefit of a well integrated program and cost rationalisation with regional logistics and available infrastructure considered from the intercept of the project allowing a system to be developed that is not reliant on large or 'bluewater' research vessels. Another novel aspect is the national integration of long term *in situ* physical and biological measurements as well as monthly sampling of hydrography and biology at two trophic levels. This program will provide critical baseline data that Australia needs to examine the impact of climate change on our marine ecosystems.

ACKNOWLEDGMENT

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Table 2. Type, units and depth for NRS monthly sampling data streams.

Data stream type	Units	Depth
CTD		
Site	Code	n/a
Time	24:00	n/a
Date	dd/mm/yyyy	n/a
Secchi Disk	metres	n/a
Conductivity	mmho	Profile 0m - 2.5m sonic depth
Temperature	°C	Profile 0m - 2.5m sonic depth
Depth	M	Profile 0m - 2.5m sonic depth
Phytoplankton		
Phytoplankton count	Cells l^{-1}	Water column
Phytoplankton biomass	ml l^{-1}	Water column
HPLC pigments	µg l^{-1} (or mg m-3)	Water column
Flow cytometry	Tbd	Water column
Zooplankton		
Zooplankton dry weights	mg per m^3	Water column
Zooplankton community	Species numbers per m^3	Water column
Zooplankton size class	µm +/- SE	Water column
Suspended matter		
Total	mg l^{-1}	Water column
Organic	mg l^{-1}	Water column
Inorganic	mg l^{-1}	Water column
Gasses and Salinity		
Dissolved inorganic carbon (DIC)	Kg	0,10,20,30,40,50m,
Alkalinity (ALK)	Mmol/kg	0,10,20,30,40,50m,
Salinity	Unit less	0,10,20,30,40,50m,
Ph - DIC	Ratio	0,10,20,30,40,50m,
Dissolved oxygen*	µmol/L	0,10,20,30,40,50m,
Nutrients		
Nitrites/Nitrate	µmol/L	0,10,20,30,40,50m
Nitrite	µmol/L	0,10,20,30,40,50m
Silicates	µmol/L	0,10,20,30,40,50m
Orthophosphate	µmol/L	0,10,20,30,40,50m
Ammonia	µmol/L	0,10,20,30,40,50m

* at selected stations only