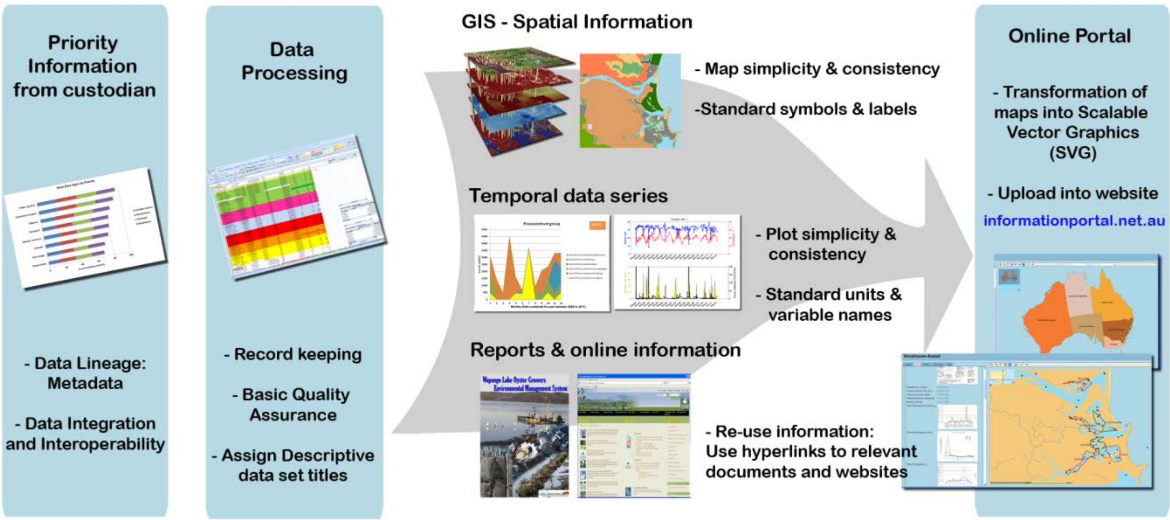
# Ensuring that the Australian Oyster Industry adapts to a changing climate

## A natural resource and industry spatial information portal for knowledge action and informed adaptation frameworks; "OYSTER INFORMATION PORTAL"

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**July 15, 2013**

FRDC Project No **2010/534**

**ISBN 978-1-74128-233-7 / ISSN 978-1-74128-234-4**

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In submitting this report, the researcher has agreed to FRDC publishing this material in its edited form.

# Contents

## Tables

## Figures

# Acknowledgments

The Oyster Information Portal (OIP) project was funded by the Australian Fisheries Research and Development Corporation (FRDC), the Department of Climate Change and Energy Efficiency (DCCEE), the Northern and Southern Rivers Catchment Management Authorities and Bega Valley Shire Council. The project was developed with the support, guidance, data and expertise from our steering and stakeholder committee members: the NSW and national oyster industry members, especially in the Camden Haven, Hawkesbury River, Shoalhaven River, Pambula and Merimbula Lakes; Northern and Southern Rivers CMAs, Bega Valley Shire Council, Shoalhaven City Council, Hornsby Council, Port Macquarie-Hastings Council, the NSW Food Authority, NSW Office of the Environment and Heritage, Peat Leith.  Special thanks go to Colin Creighton for his support and valuable input into the project; Tracey Myers for her technical support with maintaining the project's website and to Chelsea Nash for keeping the Oyster Monitoring Program going with assistance of the SRCMA and Bega Coast Oysters. NSW Fisheries and the Manly Hydraulics Lab.

# Abbreviations

ASS= Acid Sulfate Soils

DO= Dissolved Oxygen

EMS= Environmental Management Systems

HA= Harvest Areas

LGA= Local Government Agency

LPMA= Land & Property Management Authority

MHL= Manly Hydraulic Laboratory

NOW= NSW Office of Water

NRCMA= Northern Rivers Catchment management Authority

NSW DPI= NSW Department of Primary Industry

NSW FA= NSW Food Authority

OIP=Oyster Information Portal

OMP= Oyster Monitoring Program

OeH= Office of the Environment and Heritage

PMHC= Port-Macquarie Hastings Council

SQAP= Shellfish Quality Assurance program

STP=Sewage Treatment Plant

SRCMA= Southern Rivers Catchment management Authority

WQ= Water Quality

# Executive Summary

**What the report is about**

This project has delivered a proof of concept, online, interactive mapping and data delivery tool for the oyster industry and estuarine catchment managers; The Oyster Information Portal (OIP: www.oysterinformationportal.net.au). The project was undertaken at the University of Wollongong in collaboration with multiple stakeholders of the Australian oyster industry. The purpose of this portal was to demonstrate that there is a benefit of collating information from multiple agency data collections on estuaries and associated catchments and delivering it though a user friendly online portal, in order to provide unique insight into the environment and context of the oyster industry. With such information knowledge, through easily accessible and referenced spatial data, including water and food safety monitoring data, catchment data and industry and natural resource maps, the industry and stakeholders are empowered to make informed decisions and develop adaptation options for an improved and resilient industry in light climate change. The report describes the need, the concept and the development process of the OIP, as well as presents feedback and case study analyses for the data contained therein. The current portal prototype uses four estuarine systems from the northern to southern limits of NSW, including Camden Haven Inlet, Lower Hawkesbury River, Shoalhaven River and Pambula Lake.

**Background**

With the demonstrated onset of climate change, which will have a particularly large impact in the coastal zone, the predominantly estuarine and ocean embayment oyster industry faces unprecedented, unknown and unpredictable challenges. The oyster industry in Australia does not have access to estuarine and catchment information that it can use to predict, observe or respond to in light of these changes, and is left with best guessing or speculating on the causes of impacts on their productivity. Industry must be better informed about where and how key threats exist to manage risks (knowledge action) and adapt to and reduce the potential for local or regional collapse.

The concept of collating information in data portals is not new, however it has been historically difficult until information systems technology developed. Now the concept of accessible data has been facilitated by rapid technological developments, however the human and data management systems have been slow to develop and keep up. Most of the existing data portals are rarely relevant or useful to on the ground stakeholders. In contrast, the OIP was developed with a stakeholder bottom-up approach, where end-users, their needs and technical capabilities were identified prior to establishing the portal.

**Aims/objectives**

1. To source and review spatially referenced data of relevance to both the oyster industry and natural resource management of estuaries in light of climate change, and to align primary data and metadata standards.
2. To engage the oyster industry in developing the content style and delivery of natural resource and industry information in an on-line portal, including industry sourced data from Quality Assurance Programs and Environmental Management Systems.
3. To deliver a pilot, online, spatially-referenced, natural resource and industry information portal, making use of extensive primary data sources, metadata standards and national spatial data delivery initiatives.

4. Identify pathways for the spatial information portal to inform governance and statutory authorities (e.g. NRM, State and LGA), monitoring programs, strategies (e.g. oyster industry and NRM strategies) and planning policies (e.g. development application processes).

**Methodology**

Together with a majority of industry representatives and stakeholders, this project identified and selected categories of data and information sources that were relevant to both the oyster industry and estuarine resource managers in NSW and nationally. The types of data that the industry and its stakeholders require was reviewed and sourced for four catchments, resulting in a suite of extensive data sets that included local government water quality monitoring, Food Authority water and microbial testing, regional and state government catchment use and remediation, and natural resource agency data on habitat types and extent.

The oyster industry, a cornerstone of the NSW seafood industry, prioritised water quality and catchment management, and this was evident throughout the workshops and in the survey results. Similarly, water quality was a priority information need by catchment management agencies, despite the presumption that these agencies have good access to and a handle on such information. Thus, the focus for the development of the Oyster Information Portal prioritised the integration of water quality and other locally relevant data from over ten organisations with monitoring programs in a proof of concept, online portal for four oyster growing areas in NSW: Camden Haven Inlet, Lower Hawkesbury River, Shoalhaven River and Pambula Lake. This prototype was developed in a GIS environment and delivered through an online website with graphical interpretation of spatial and temporal, environmental and industry data. Additional information and links to climate projections, governance and research outputs also formed part of the OIP to provide a more holistic and integrated synthesis of information related to the catchment. The oyster industry and stakeholder representatives were liaised with throughout the development of the OIP.

**Results/key findings**

This project demonstrated that the extent of data and information relevant to the oyster industry and estuarine management is extensive. However this information is dispersed across diverse organizational structures with independent mandates and objectives; thus the data and information is effectively inaccessible to stakeholders such as the oyster industry as well as managers there-of. In addition there has been limited analysis and interpretation of this data even within custodian organisations, and therefore the true value of investment has not been realized. Thus the opportunity to monitor for temporal shifts that might be related to climate change and that might affect the oyster industry was unexplored.

The Oyster Information Portal prototype was successfully designed and integrated data from multiple stakeholders for a synthesis and delivery of this previously inaccessible data. The online format had been developed with and was therefore suitable to the use of oyster industry representatives themselves, as well as stakeholders such as local government and other State Authority staff. A nationwide context of the oyster industry is presented spatially and users can then gradually soon in to their local estuary, from the four cases developed, and then to their own lease. From here they can identify monitoring points from multiple agencies in close proximity to their lease, as well as spatial maps of catchment condition.

**Implications for relevant stakeholders**

The key implication of the Oyster Information Portal was that it was useful to the oyster industry and government management agencies alike. The OIP demonstrated and provided access to multi-jurisdictional data and information from each estuary for the first time; thus an oyster lease could be found in an estuary and water and catchment data relevant to that lease location could be found. Some examples of analytical outcomes and interpretation from data provided through the oyster information portal was demonstrated. These range from detailed and statistical analysis of core data that showed, for example, an instance of a decadal shift in harmful algae bloom dominance; locational variability in the productivity and condition of oysters; to referencing of locational concerns of the oyster industry in managing the development of the catchment. For these reasons and more, the development of the OIP was supported by key catchment stakeholders that recognize the need for a tool that integrates existing information to inform response decision making and long term adaptation.

In addition, it was identified that a limiting set of data and information that might render the industry vulnerable today, as well as in light of climate change, was an understanding of species and genetic resources within the industry. Analysing this data revealed substantial genetic vulnerability within the existing industry, but also an untapped opportunity for increased resilience and adaptation for the oyster industry through improved recognition, use and management of genetic resources.

**Recommendations**

A core issue in progressing the concept of OIP across the whole of the Australian oyster industry is the logistical coordination of data from multiple jurisdictions. Thus the long term viability of this concept relies on the development of an agency mandate to identify, establish data management processes and quality control the delivery of data to storage systems; thus providing identifiable data that can consequently be accessed. It was evident that coordinating individuals or agencies to adopt in-house management practices that could keep up to date with the latest requirements and technological developments in delivering accessible data would be inefficient, and is probably not feasible. Rather, one nominated node of government is required to coordinate the multi-jurisdictional data management systems and to provide support to multiple agencies' that have invested time and effort in the collection of data.

Such government nodes are already in existence, however the extension to on the ground data custodians has not been made. Considerable investment has been made on standards of the data management practices and metadata creation systems; but for a return on investment without outcomes such as the OIP to be realised, the final logistical challenge of establishing data processing and management practices must be overcome. The majority of this data is publicly funded and as such can be delivered or filtered to deliver value back to industry and society under diverse forms of creative commons licensing, and this is a minor issue compared to the logistical one.

Once data can be coordinated and deposited in this way, there are a wealth of information technology systems that exist and that can source and incorporate this data into analysis systems targeted to specific user groups. These systems are under continual development across a range of interests, sectors and user groups. Here the OIP was delivered through an isolated and simple technology platform that could deliver and demonstrate the concept. In addition a Business Intelligence System dashboard technology adopted one instance of the OIP to demonstrate the outputs from a more sophisticated system. This system provides provide control over user access conditions, but importantly can provide defined and customised information across selected data sources within an analytical environment that is user driven. For example, a user may wish to correlate water quality data with catchment conditions or events within a specific time frame or set of locations. Thus once data is accessible the technology is available to deliver.

A one size fits all strategy for adapting to climate change is not realistic for the oyster industry as a whole. Regionally specific stressors will affect the industry differently across estuaries and nationally across states. Local resilience will require local information and local solutions. However the common need to access information from within a framework that is locally relevant and nationally positioned is required. The OIP demonstrates the usefulness of a scalable spatial-information tool for knowledge action and adaptive responses to catchment and climate change.

## Keywords

***Saccostrea glomerata*, *Crassostrea gigas*, estuaries, water quality, catchment, online information systems**

# Introduction

The oyster industry recognises that its success is interwoven with the environment, including the delivery of productive, healthy waters from the catchment and ocean. As such the industry is vulnerable to catchment impacts and changes in oceanic condition as a result of global warming. During the last decades, the oyster industry has also been competing with increasing activity in the coastal catchment areas for space on land and in water, and has suffered from decreasing water quality and increasing extent of disease outbreaks linked to coastal activities. This has been reflected in their annual production for the last few decades (Figure 1). Sydney Rock Oyster (*Saccostrea glomerata*, SRO) production in NSW reached its peak in the mid 1970’s producing around 140,000 bags of oysters/year. Since then, annual production has been in a state of steady decline and the industry currently produces around 45,000 bags/year (NSW DPI, 2011). The annual rate of decline has been approximately 2,400 bags (~3.2 million oysters) since 1970.

Despite 32 estuaries in NSW producing SRO, most of the historical production was associated with a few large oyster producing estuaries such as Port Stephens, Georges River, Wallis Lakes and the Hawkesbury River. In recent years, some of these large rivers such as the Georges River (1995) and the Hawkesbury River (2005) were affected by QX Disease that completely wiped out the production of SRO in these rivers. Other diseases like Winter Mortality have also threatened the industry in other rivers. However, in most cases impacts from this disease are still not accurately quantified and linkage to potential environmental degradation is yet to be established. The response has been to select few surviving oysters for breeding programs, or to convert production to Pacfic Oysters (*Crassostrea gigas*). However Pacific Oysters are not a panacea; the Pacific Oyster Mortality Syndrome (POMS) has devastated the production of oysters in three NSW rivers in the last two years (NSW DPI 2013). Regardless of the disease mortality events, the oyster industry is still losing an increasing number of oysters each year (~10-30% per annum depending on the estuary, Nash and Rubio, 2012) from unexplained mortalities, which is much higher than previously thought (10% over the commercial life cycle, O'Connor and Dove, 2009). Even when production data from QX disease highly-impacted estuaries are removed from the overall oyster production data for NSW, the declining trend is still apparent, indicating that there are other aspects impacting oyster production.

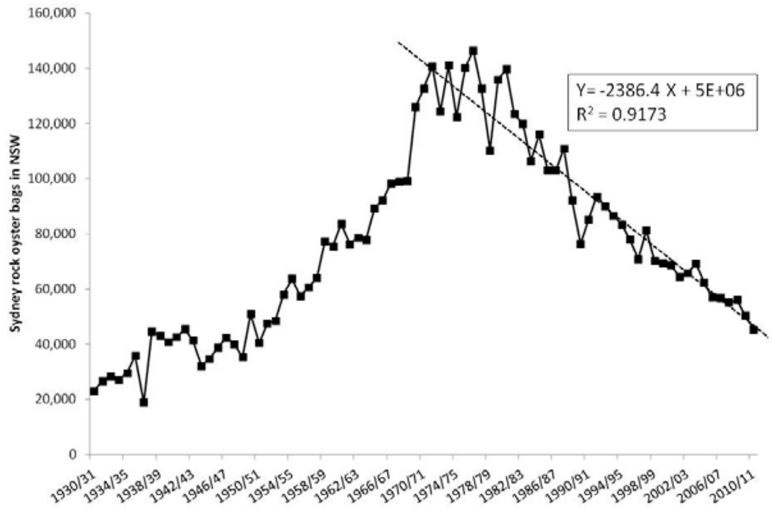



**Figure 1: NSW Sydney Rock Oyster production through time. Linear regression fitted to decline in production from 1970 (data source: NSW DPI Fisheries annual aquaculture reports)**

To date, no specific causes have been attributed to the overall decline in oyster production. A series of alternative causes have been proposed such as the introduction of feral oyster species (Pacific Oysters, *Crassostrea gigas*) competing for resources with the Sydney Rock Oysters, degradation of water quality caused by anthropogenic catchment activities, invariant market prices of oysters despite inflation and poor oyster management practices. Over time there has been also a reduction in active lease areas, which in some cases has been attributed to environmental degradation (White, 2001). Thus there is probably no single, attributable cause to production decline and, analogous to coral reef declines, there are multiple stressors on the industry which will include the encroaching climatic shifts.

The last 12 years has seen a small reduction in the rate of decline of production compared with the rate calculated in 2001 (3,000 bags/year, ~3.6 million oysters (White, 2001). This early indication of improvement might be associated with recent governance initiatives in managing the industry. Since 2006, priority oyster leases have been protected by the NSW Government under the Oyster Industry Sustainable Aquaculture Strategy (OISAS) in order to support the long term sustainability of the industry (NSW Department of Primary Industries, 2006). But threats to oyster production that relate to water pollution, in particular human faecal contamination, still threaten the industry with continual catchment development. In 2003-2005, most of the oyster producing estuaries were classified under the NSW Shellfish Quality Assurance Program (SQAP). Specific harvesting management schemes were mandated according to historical pollution events, localised rainfall patterns and catchment processes and development. In addition, a significant number of on-ground catchment works and improved oyster industry practices (i.e. implementation of estuary-wide oyster industry Environmental Management Systems) have recently been implemented. Thus if a suite of management strategies can serve to increase resilience in the oyster industry, then this is one adaptive opportunity that needs to be harnessed and well informed.

A resilient oyster industry will be better prepared to tackle the impacts associated with climate change. In NSW there are already measureable changes to air and water temperature as well as patterns in the delivery of precipitation or storm events (The Climate Commission, 2011). These changes, along with catchment stressors, will affect salinity regimes, catchment run-off as well as changes to the incidence of harmful algae blooms and the length and frequency of harvest closure periods. As a result, the oyster industry in Australia may face unprecedented challenges in the future, but also more relentless battles with familiar challenges. A better understanding of climate change impacts is vital so that the industry is better informed to manage risks, adapt and minimise negative impacts. Adaptation will not only require better knowledge of the natural resources, but a framework to integrate knowledge of the whole socio-ecological system within which the oyster industry operates, including bio-physical, industry and governance sectors.

The oyster industry has recently identified key climate change related challenges that are likely to affect their industry. These challenges were recently summarised by researchers at the University of Tasmania and the national Climate Change Adaptation research Facility; “Climate change adaptation in the Australian edible oyster industry: an analysis of policy and practice” (Leith and Haward, 2010). A key priority identified by the industry was to increase monitoring programs and to gain access to existing environmental monitoring data so that information can be related to industry performance historically and into the future. It is also in the interests of catchment managers to access, analyse, interpret, learn and inform management based on such monitoring data.

A challenge however is that although millions of dollars are spent on a wealth of coastal monitoring, and thus extensive data on water quality and catchment activities exists, it is rarely analyzed or considered across organizational custodians nor for interpretation towards informed management of each individual water body. Of importance is that the data is effectively inaccessible by third parties outside the custodian organisations. Thus the returns on investment from coastal monitoring are not realized, with poor availability of cohesive information within each waterway. Initiatives to overcome this loss of value have been initiated but often fallen over due to cross jurisdictional issues, restrictions of I.P. and lack of direction establishing protocols for best practice in data management and dissemination.

# Need

A lack of integration between bio-physical knowledge and industry knowledge currently constrains effective management of the oyster industry, and farmers are often left with unanswered questions or anecdotal information to account for the causes of reduced productivity from year to year. There is currently no uniform framework with which to deal with the diversity of coastal monitoring initiatives and provide available information to the oyster industry.

A broad consensus is evident across scientists, coastal industries and natural resource managers, that the coastal zone is at high risk for the full range of climate change impacts from land and sea (Simms and Woodroffe, 2008). Thus the oyster industry has a most urgent need to achieve practical adaptive solutions to shifting and variable environmental conditions by being informed about the historic, current and long term trends (NSW DPI Fisheries comment, industry feedback; Simms and Woodroffe, 2008; Leith and Haward, 2010). A common need by both the oyster industry and managers thereof is the the collation of spatial information about climate change threats, industry sites, production and management and, essential environmental resources (water quality, primary production and ecological supporters of aquatic ecosystems) to provide for informed adaptation strategies. Leith and Haward (2010) summarized specifically that the priority needs include:

- a program of coastal and estuarine monitoring in which oyster growers, regional universities and regional NRM authorities are partners
- continued development of knowledge-action networks of growers, industry bodies, scientists, regional NRM agencies and representatives of state and local government and;
- provision of clear and concise information that allows reciprocal understanding of the process of oyster farming and the needs of growers… and of government regulatory and approvals processes.

Therefore this project addresses the recommendations above by the development of a proof of concept of an Oyster Information Portal (OIP) which provides multijurisdictional information, often derived from monitoring data, and information of regulatory frameworks.

# Objectives

1. To source and review spatially referenced data of relevance to both the oyster industry and natural resource management of estuaries in light of climate change, and to align primary data and metadata standards.
2. To engage the oyster industry in developing the content style and delivery of natural resource and industry information in an on-line portal, including industry sourced data from Quality Assurance Programs and Environmental Management Systems.
3. To deliver a pilot, online, spatially-referenced, natural resource and industry information portal, making use of extensive primary data sources, metadata standards and national spatial data delivery initiatives.
4. Identify pathways for the spatial information portal to inform governance and statutory authorities (e.g. NRM, State and LGA), monitoring programs, strategies (e.g. oyster industry and NRM strategies) and planning policies (e.g. development application processes).

# Methodology

To achieve an industry relevant information system, the development of a strong network was established with the Oyster Industry, governance agencies that are responsible to or for the oyster industry and organisations that are custodians of relevant data. At this proof of concept stage and with knowledge of the extent of data and information available, it was established that selected estuaries, rather than broad inclusion of many rivers, was a priority to demonstrate the extend of data and the usefulness of it; thus four oyster growing areas in NSW were chosen to demonstrate the value of an Oyster Information Portal (OIP). The four sites were chosen as described below. Since the oyster industry relies on processes occurring in the catchment and in the estuary itself, there was a wide range of information that was of relevance to the portal. Thus the methods of prioritization and selection of data is also described. The last section of the methods, the conceptual framework used for data compilation, management and integration into a web-based data portal including the process followed for knowledge transfer and dissemination is described.

The prototype Oyster Information Portal concept was developed within the context that it could be extended to incorporate all oyster producing estuaries and bays in Australia. Thus a first scale of the portal reviewed and consolidated statewide information about the oyster industries in each state of Australia.

## Project Sites

Of the current 30 oyster producing estuaries in NSW, 18 of them sustain a relatively consistent level of production. Industry members from these 18 estuaries were approached seeking expression of interest as participants of this project. Local councils, state government agencies and other catchment stakeholders were also approached as the success of the project would rely on the interest of these stakeholders as well as the provision of data from custodians. In addition to the interests identified by the oyster industry and stakeholders, a diverse representation of geographical features, catchment processes, diversity in oyster production, industry group size and current major impacts affecting the local industry were considered. The four selected oyster producing estuaries were the Camden Haven, Hawkesbury River, Shoalhaven River and Pambula Lake (Figure 2). These estuaries correspond to the following Local Government Areas (LGA) within New South Wales (NSW): Port Macquarie-Hastings Council; Hornsby Shire Council; Shoalhaven City Council and Bega Valley Shire Council. A summary of the main stakeholders involved in each LGA, including key features describing their approach and attitude towards the oyster industry and catchment health, are summarized in Table 1 .

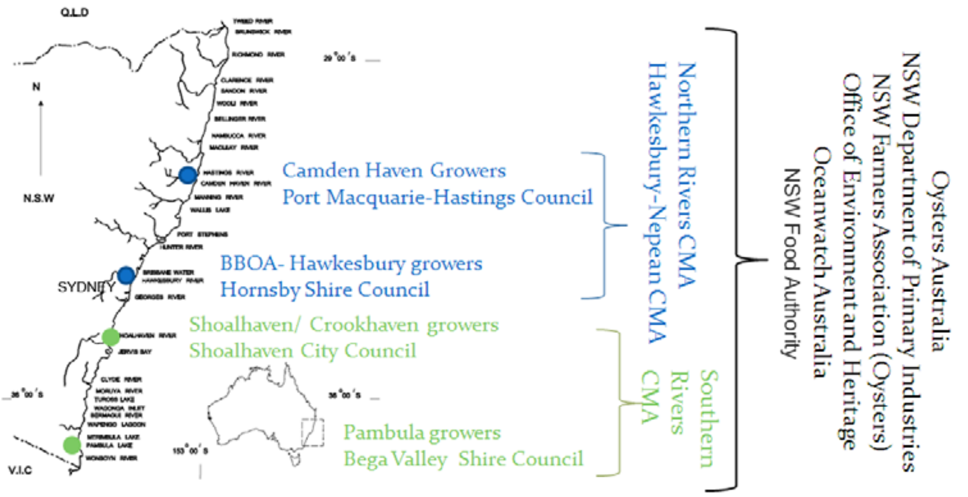



**Figure 2. Geographical location of the 4 selected areas in NSW where the Oyster Information Portal has been developed in detail.**

Table 1 : Summary table outlining major stakeholder organisations for the 4 LGAs of the project including general catchment activities and commitments in the selected estuaries

| State | LGA | Stakeholders | Involvement in catchment/ industry activities |
|---|---|---|---|
| North NSW | Port Macquarie Hastings | Local council (Port Macquarie- Hastings Council) | -Proactive council in environmental monitoring. Recently undertaking intensive aquatic monitoring program (EcoHealth 2011).<br>-Interested in collaborate further with their local oyster industry<br>-Most of their monitoring focuses on bacteriological pollution events<br>-Supportive of the project concept idea -letter of support provided |
| | | Northern Rivers Catchment Management Authority | -Water /catchment data from NRM monitoring<br>-Strong collaboration with local councils<br>-Willing to get more involved in projects wirh the oyster industry<br>-Interested party in project idea - cash contributor |
| | | Oyster industry (Camden Haven Growers) | -Oyster spat producers mainly<br>-Medium size industry (15 growers)<br>-Proactive industry group<br>-Group committed to improve their practices and to ensure good water quality and long security of their industry (ie. Environmental Management System developed for the group) |
| Mid NSW | Lower Hawkesbury | Local council (Hornsby Shire Council & Gosford City Council) | -Most proactive councils in NSW in regards to monitoring programs (long-term monthly water quality monitoring, telemetric real-time water quality probes; annual reporting)<br>-Large urban development in areas of the catchment; large catchment areas; large recreational and commercial fishing community<br>-MOU establish between HSC and the local oyster industry<br>-Supportive of the project -Letter of support provided |
| | | Hawkesbury Nepean Catchment Management Authority | -Group based in the upper catchment of the Hawkesbury River<br>-Most activities and catchment work concentrates in the upper catchment |
| | | Oyster industry (Hawkesbury) | -Medium size group now producing Pacific Oysters after a dramatic disease outbreak that turned the, at the time, second larger oyster producer in NSW, to nill production within a year. Consequently, the current group is consiered very resiliant.<br>-Proactive group collaborating with researchers<br>-Just got accreditation to export<br>-Group committed to best practice implemetation and healthy catchments (ie. Environmental Management System developed for the group) |
| South NSW | Shoalhaven | Local council (Shoalhaven City Council) | -Small environment section in council managing a large area but keen to share information and to gain knowledge from research projects<br>-Group interested in collaborating in projects for the benefit of their local oyster industry<br>- Need for improved sewage and flood mitigation framework<br>-Supportive of this project concept idea -letter of support provided |
| | | Southern Rivers Catchment Management Authority | -Key stakeholder and project collaborator interested in MER monitoring, catchment works and healthy catchments<br>-Strong partnerships with the local oyster industry<br>-Proactive group involved in innovative research projects<br>-Strong supporter of this project -cash contributor |
| | | Oyster industry (Shoalhaven/Crookhaven) | -Medium size industry that have diversify their production by growing Sydney rocks and Pacific oysters.<br>-Serious problems with winter mortality disease, environmental flows releases and poor management of flood gates<br>-Group committed to best practice implemetation and improved water quality in the river(ie. Environmental Management System developed for the group) |
| Far South NSW | Bega | Local council (Bega Valley Shire council) | -Small environment section in council managing a large area but keen to gain knowledge from research projects<br>-More interested in catchment works than monitoring programs<br>-Strong supporter of this project -cash contributor |
| | | Southern Rivers Catchment Management Authority | -Key stakeholder and project collaborator interested in MER monitoring, catchment works and healthy catchments<br>-Strong partnerships with the local oyster industry<br>-Proactive group involved in innovative research projects<br>-Strong supporter of this project -cash contributor |
| | | Oyster industry (Pambula) | -Medium size industry currently increasing overall production as a result of large investment in capital<br>-Proactive group and collaborator in research projects<br>-Growers with water quality experience (community monitoring programs in place)<br>-Group committed to best practice implemetation and improved water quality in the river(ie. Environmental Management System developed for the group) |

# Information needs – Consultation process

For the Oyster Information Portal to be of most relevance to the oyster industry and its stakeholders, a process of consultation and feedback with industry and the stakeholders was conducted throughout the project. This process was facilitated through onsite presentations, questionnaire and workshop formats, bimonthly steering committee meetings, demonstrations and feedback questionnaires, online surveys as well as ongoing communication through newsletters and open email and telephone communication.

The consultation process focused on the following stages and aspects throughout the development of the project:

- Defining the concept of a spatial information portal for natural resources and for oyster data.
- The selection of relevant data to include in the portal.
- Feedback on the visual representation of the data output and the operability of the portal through its development. At each workshop, teleconference or meeting, feedback was collated on the needs of industry and stakeholders to ensure that the data was in a user-friendly format and of value to industry decision making.
- Considering scenarios that impact the oyster industry and testing ways that the portal can assist in informing the management of these.
- Discussions about future data best practice management to ensure information can be easily disseminated
- Discussions on best approach towards the future development of the portal prototype

## Steering and Stakeholder Committees

The primary Steering Committee comprised primarily governance agency representatives from nine organizations (Appendix III: Steering Committee Members) and met every two months to discuss the content and progress of the development of the Oyster Information Portal. A Stakeholder group comprised another 37 stakeholder agencies (Appendix IV: Stakeholder List) of the Australian oyster industry and/or organizations involved in environmental data management protocols or development of data portals. The stakeholder group was continuously updated through a newsletter network and liaised with on an as-need basis.

## Industry workshops

A total of 12 oyster industry workshop consultations were undertaken with the aim of identifying issues, presenting and ranking data and information categories, testing the portal interface and discussing the best approaches and applications to make use of the OIP for the management of oyster businesses and adapting to environmental change (Figure 3). Three rounds of industry workshops took place at each of the study areas in NSW (Camden Haven, Hawkesbury, Shoalhaven and Pambula Lake) during the two years of the project. National industry and stakeholder consultation was undertaken at an additional workshop in conjunction with the 4th International Oyster Symposium to discuss the future potential and context for a national scale-up of the OIP. This workshop was attended by representatives from all oyster growing states except the Northern Territory and Western Australia.

**Camden Haven workshop** | **Hawkesbury River workshop**

**Shoalhaven River workshop** | **Pambula Lake workshop**

**Figure 3: Oyster industry workshops at which the Oyster Information Portal was demonstrated**

## Identification of data sources and custodians of data

The workshops provided an opportunity to both open the floor to identification of key issues facing the oyster industry, as well as provide a categorization of identified data sets and information from numerous estuarine monitoring initiatives to be prioritized in light of key issues. The categories that were ranked and prioritized through questionnaires used in the industry workshops included:

- *Water Quality* – e.g. pH, salinity, temperature
- *Climate Impacts* – e.g. seasurface temperature, storm events, flood lines etc.
- *Industry related information* – e.g. Food safety results, lease areas and conditions
- *Research outcomes* – e.g. location or broad context research outcomes
- *Natural Resource information* – e.g. estuarine features, sediments, seagrass
- *Catchment impacts* - e.g. sewage events, land use etc.
- *Spatial maps* – e.g. estuary map, acid sulfate areas, catchment use etc.
- *Governance information* – e.g. jurisdictional information, governance resources etc.

While within each category a list of examples of available types of data was provided and these were also ranked in order of priority. There was opportunity for stakeholders to identify additional types of information needs that hadn't been considered previously. Also, stakeholders who were unable to attend meetings were provided the opportunity to undertake the survey electronically as well.

# Conceptual framework for data integration into a web-based portal

## Data Management

After data was prioritised by industry and catchment managers, relevant datasets were sourced from the various custodians and catalogued in a data management system that included a file of unaltered, original custodian data. Data and information was then reorganised based on best practice standard data management protocols (Hook et al., 2010) as shown in Figure 4. In most instances, data was received in poor and/or inconsistent organisation and there was a lack of background information or metadata.

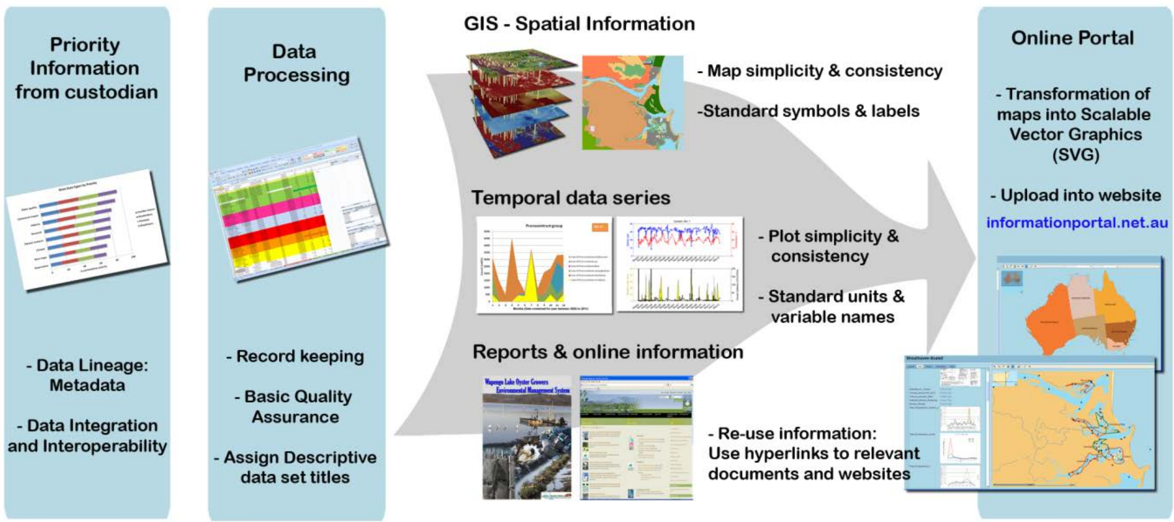



**Figure 4: Schematic of the Oyster Information Portal workflow**

## Metadata

It is now mandated that government and research data should follow standards of metadata creation for unique data sets (Table 2), yet few organisations have adopted this within data management systems to date. A review of the available metadata proforma was undertaken and intensive communication was established with the NSW State metadata Coordinator from the NSW Land & Property Management Authority/ Land & Property Information (Mr Greg Windsor). Despite the fact that the Marine Community Profile (MCP) proforma appeared to be more specific for the environmental information contained in the OIP, the interface (ANZ-MEST) to generate the MCP metadata file was extremely complicated and laborious. Since the implementation of metadata creation was a new concept for data custodians, a more user-friendly standard was used to develop meta data according to the NSW Natural Resource Metadata Policy (Table 2 ). Consequently the ANZLIC Met Tool software was chosen to create metadata files because it is user-friendly, it is freely available, and it follows ISO 19115/19139 standards. Metadata files were created in collaboration with the data custodian using ANZLIC Met tool and meeting the NSW Government- State records requirements as per http://www.records.nsw.gov.au/recordkeeping/government-recordkeeping-manual/guidance/recordkeeping-in-brief/recordkeeping-in-brief-18.

Metadata files created are easily transferable across data portals if needed. All data sets included in the data portal are linked to a 'Parent metadata' file which contains information about the content, quality and accuracy, currency and availability of the data, including links to final reports or websites where the data has been summarised or disseminated. Other data portals require metadata files for each parameter measured as part of the program so that more specific information for that variable is captured. Since this project is a prototype, parent metadata information was sufficient and could a number for variables within a sampling program, for example, pH and water temperature. Future development of individual parameter metadata can be linked to the currently developed parent metadata file, within which updates and data management flow systems can be identified.

At present and in contrast to point data files, most of the spatial layers contained in the OIP as base maps are not linked to metadata files, as the current ESRI metadata profile does not follow ISO 19139 standards. In general, most of the data custodians have not generated metadata files for the spatial information and developing such files now is difficult. Currently, conversion software is under development so that metadata information that might exist in ESRI created files, it can be transformed to ISO standards. At the current time and considering the project resources, it was decided that this specific type of metadata, for example land area, was not going to be pursued.

**Table 2 : NSW Natural Resource Metadata policy**

**Metadata Policy (http://www.nrims.nsw.gov.au/policies/metadata_policy.html )**

**1. All natural resources datasets collected and maintained by New South Wales agencies will have metadata.**

**2. Data custodians are responsible for creating and maintaining metadata for their datasets.**

**3. Metadata records will conform to the current Australia New Zealand Land Information Council (ANZLIC) standard with the addition of any extensions agreed at State level.**

**4. Extensions agreed at State level should be selected from the elements of ISO Standard 15046-15: Geographic Information - Part 15: Metadata (draft) wherever possible.**

**5. Metadata records will be made available by data custodians for inclusion in State and national directories in the specified ANZLIC transfer format(s).**

**6. Metadata records will be made available through national and State directories at no cost to users.**

**7. Metadata records will form part of each data supply.**

**8. To ensure that data recipients are able to use supplied data most effectively, all transfers of digital spatial data should be accompanied by the additional metadata elements identified in the quality assurance checklist.**

Slowly agencies are adopting data and metadata management standards within the NSW data management framework. As part of a data gathering exercise, the final repository for the data should also be clearly indicated at the outset. In the case of the OIP framework itself, additional metadata was created to describe the concept, content and process of developing the OIP.

## Data conversion into an online format

Most of the data sets included in the OIP belong to relatively new monitoring programs as data custodians found it hard to access historical data, due to it being lost or more usually because it was not stored in readily accessible formats (e.g. paper documents rather than electronically). This is a reflection of the legacy of poorly managed and maintained data, but also that a slow transition to avoid such future scenarios is underway and that the concept of data portals such as the OIP can now be realized practically.

Once data was correctly formatted and checked in spread sheets, it was processed through a workflow (Figure 4). Spatial information was processed and amalgamated hierarchically through ESRI products for visualization. Temporal, environmental data-sets were plotted and linked from a coordinate on the spatial layers of information, and presented in summary tables for display of the data range, trends and variability. All data was maintained within identifiable categories of custodianship and raw data was not made available due to the current limitations of licensing of raw data to a broad audience. Creative commons licensing that is emerging to solve these issues is demonstrated in a case study below. Published information was also hyperlinked from the information displayed, or made available through downloads.

The final combined package of designed maps and structured data and information was then transformed into scalable vector graphic (SVG) files using the Mappetizer software (uismedia; http://www.uismedia.de/index.html) which could then be uploaded to an online website to deliver a user-friendly web-mapping data portal.

# Results

## Issues & priorities of the oyster industry and its stakeholders

The information presented in this section was gathered from 56 oyster stakeholder participants including growers (90%) and representatives from industry regulators, policy administrators and researchers as part of the first round of industry workshops and meetings. Of the project area industry members, approximately 80% were represented at the workshops demonstrating strong engagement in the Oyster Information Portal concept.

Oyster industry stakeholders identified five key issues that they were concerned about for the long-term sustainability of their industry. The issues in order of importance were current issues and were consistent across most of the oyster growing areas: 1) chronic impacts on water quality (climatic, catchment or otherwise), 2) disease outbreaks in general with current concerns on the Pacific Oyster Mortality Syndrome (POMS); 3) sales and marketing including branding, product quality and prices and 4) unreliable hatchery seed supply. These priorities were common across all states. Additional aspects impacting the security of the oyster industry were the occurrence of pollution events (sewage overflows and urban run-off events in addition to more chronic water quality issues identified above), a lack of knowledge of carrying capacity and productivity of oyster leases, overall profitability of the oyster industry, poor communication across industry members and industry cooperation (see Table 3 ).

Different oyster growing states are influenced by different processes and this was reflected in some of the workshop outcomes. For instance, the oyster industry in South Australia is less influenced by catchment impacts as oyster growing areas are mainly supported by oceanic productivity. In contrast the NSW oyster industry relies nearly entirely on the quality of water and food from the catchment. Thus oceanic shifts should in theory impact the South Australian industry to a greater degree, while NSW will be affected by climatic shifts and storm events to a larger degree. Similarly there were issues within NSW that were specific to the local context only; for example the northern rivers farmers were concerned about the developments of coal seam gas mining, while southern rivers farmers had to deal with dams or a legacy of floodplain engineering.

**Table 3 : Major impacts to the Australian oyster industry identified by industry stakeholders (n=56) from NSW, TAS and SA**

| Impacts to the oyster industry | % agreement |
|---|---|
| Impacts on Water Quality | 14.06% |
| Disease in general (Mudworm, QX, SAMS and others) | 7.81% |
| Sales + Marketing (branding, product quality & price) | 7.03% |
| Disease - specific POMS | 6.64% |
| Hatchery seed supply | 5.86% |
| Pollution | 3.52% |
| Carrying Capacity/ Productivity of leases | 3.13% |
| Profitability | 3.13% |
| Sewage overflows | 2.64% |
| Government & regulation & fees | 2.64% |
| Communication across growers/ industry co-operation | 2.26% |
| Urban run-off, | 2.26% |
| Sustainability | 2.26% |
| Sewage overflows | 2.64% |
| Coal Seam Gas mining | 1.89% |
| Climate Change/ weather patterns | 1.89% |
| Employment/ lack of skilled workers | 1.89% |
| Floods & weather events | 1.89% |

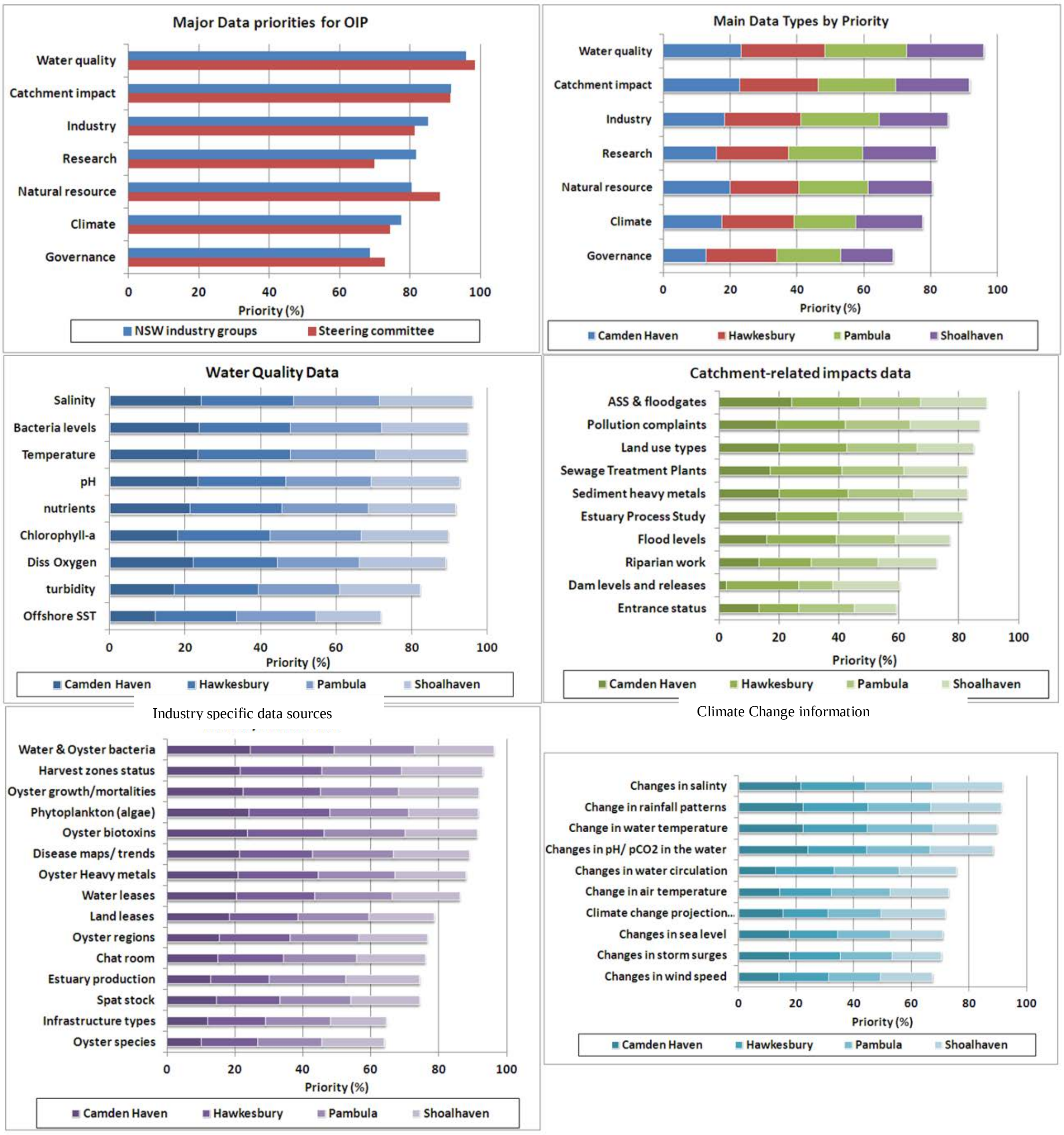
## Priorities of catchment managers

Natural Resource Managers at workshops or members of the steering committee were asked to fill in the same questionnaire that industry members used, to provide feedback on perceived industry issues as well as issues for their own agendas. The top three priorities for NRM groups managing coastal catchments were sewage management activities including sewage overflows and onsite septic system management, other impacts on water quality and catchment land use and planning/activities (Table 4 . This was follow by specific issues such as riparian management, including cattle exclusion via fencing, acid sulfate soils, upstream land management and urban run-off (e.g. storm water, siltation, erosion).

**Table 4 : Natural Resource Management priorities in relation to perceived impacts on the oyster industry and general issues of estuaries & coastal catchments**

| Catchment Priorities from NRM agencies | % agreement |
|---|---|
| Sewage management/overflows/Septic | 10.26 |
| Impacts on Water Quality | 7.69 |
| Land use planning/ use | 7.69 |
| Riparian management | 5.13 |
| Cattle exclusion (fencing) | 5.13 |
| Acid Sulfate Soils | 5.13 |
| Upstream land management (nutrients/ sediment loads) | 5.13 |
| Urban run-off/ storm water | 5.13 |
| Siltation (gravel roads run-off)/ erosion | 5.13 |
| Valuation of estuarine ecological services | 2.56 |
| Floods & weather events | 2.56 |
| Harmful Algae Blooms (HABs) | 2.56 |
| Chemical/ heavy metals | 2.56 |
| Catchment general environmental processes issues | 2.56 |
| Lack of enforcement (regulation/ compliance) | 2.56 |
| Biosecurity (inc controlling diseases/pest) | 2.56 |
| Population pressure increase | 2.56 |
| Funding availability to solve catchment problems | 2.56 |
| Flood mitigation drains and floodgates | 2.56 |
| Governance process in estuary management | 2.56 |
| Upstream water usage and flow management | 2.56 |
| Management of wastewater infrastructure | 2.56 |
| Access to waterways | 2.56 |
| Habitat quality | 2.56 |
| Community, landholder & industry participation in NRM | 2.56 |
| Clearing of landscapes | 2.56 |
| Reversion of lake back to freshwater | 2.56 |

Considering the vast amount of relevant information that already exists in relation the issues identified and that could be included in the OIP, categories of data and information were prioritized for inclusion in the proof of concept OIP. Six major categories were ranked on importance to industry members and catchment managers (Figure 5) and both groups prioritised water quality and catchment impact information. As such, data related to water quality and catchment impacts formed the base of the OIP for its prototype phase and subcategories were prioritized within those groups to better select the information that was requested from custodians; primarily Local Government Authorities and the Shellfish Quality Assurance Program.



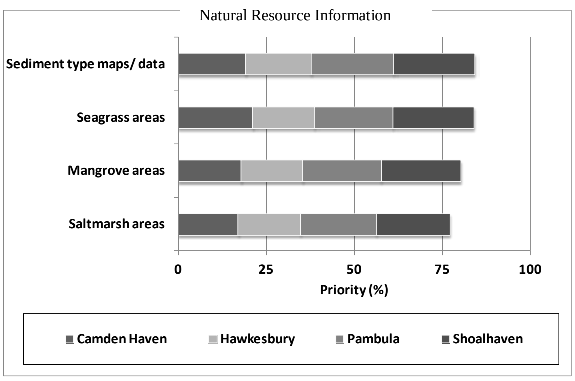




**Figure 5: Data categories and variables ranked by the oyster industry and stakeholders at consultation workshops to be included in the OIP**

In contrast to water quality information, ranking in relation to catchment impacts showed high variability across oyster growing areas (Figure 5). This reflects the unique geology, estuary types and catchment pressures of each oyster growing estuary. For example, dam water release information was of a high priority to the two estuaries with dams (Hawkesbury and Shoalhaven Rivers), and estuary entrance status was only important for growers with cultivation methods in Intermittently Closed and Open Lakes (ICOLLs). In contrast, acid sulfate soil information was more important in those catchments with extended flood plains like the Camden Haven and Shoalhaven.

A third major priority was further information collected by the NSW oyster industry through the NSW Shellfish Quality Assurance Program which includes species level taxonomic identification of harmful algae and harvest closure and opening regimes. Overall the requested types of data and information identified for inclusion in the OIP was diverse, but the priorities were clear and useful in scheduling the acquisition of data and information from targeted custodians.

## Data sources and custodians of data

Custodians of data were identified for the data types prioritized for the OIP (Table 5 ). Of importance was the lack of metadata information that would have assisted with the discovery of data. Without metadata, detailed communication exchanges were required with the data custodians to understand what and where data related to.

### Creation of metadata

"*A metadata repository is a key enabler to* ***gathering, retaining and disseminating knowledge****. It is a:*

*• place* ***to view ANZLIC-compliant metadata***

***• searching mechanism*** *for metadata.*

*IT DOES NOT HOLD YOUR RESOURCE.*

***Metadata should be readily discoverable*** *even if the resource is restricted*"

(ANZLICC The Spatial Information Council - http://anzlic.org.au/)

Government agencies and research organisations in Australia and within states are slowly aiming to integrate metadata creation and maintenance as part of their data management workflow. However in NSW, few are aware of the simple, freely available software that is available and meets Australian Standards for metadata creation, and there little implementation of procedures with respect to how and where to upload data and metadata within the NSW or Australian data management framework. Thus this project required that discussions with data and information custodians were held to identify what data existed, and a first step was to create metadata for those data sets.

At a national level, the Office of Spatial Policy has endorsed the adoption of the ANZLIC Metadata profile:
(http://spatial.gov.au/system/files/public/resources/anzlic/ANZLICmetadataProfileGuidelines_v1-2.pdf)
for use by Australian Government agencies in November 2007. ANZLIC is the "peak intergovernmental organisation that provides leadership in the collection, management and use of spatial information in Australia and New Zealand" (http://anzlic.org.au/). This Metadata Profile is based on the International Metadata Standard ISO 19115 and ANZLIC has developed a number of

resources, including software (http://spatial.gov.au/resources/metadata),that will facilitate the creation of ANZLIC-compliant metadata records for new data of from previous types of metadata records.

Once created, the metadata needs to be centrally stored to become discoverable. At present, ANZLIC Met Tool guidelines suggest that metadata created in NSW should be uploaded to the NSW Spatial Data Catalogue which is managed under the Australian Spatial Data Directory through the Office of Spatial Data Management (Figure 6). In parallel, metadata created through ANZLIC Met Tool could also be uploaded to the NSW Land and Property Management Agency (LPMA) data repositories. Currently these systems have not been fully resourced to service the need for uploading of metadata from custodians across the state; however these systems are being established and it is necessary that agencies progress the adoption of metadata creation and management practices so that the streamlining processes for effective discovery of data can be achieved.

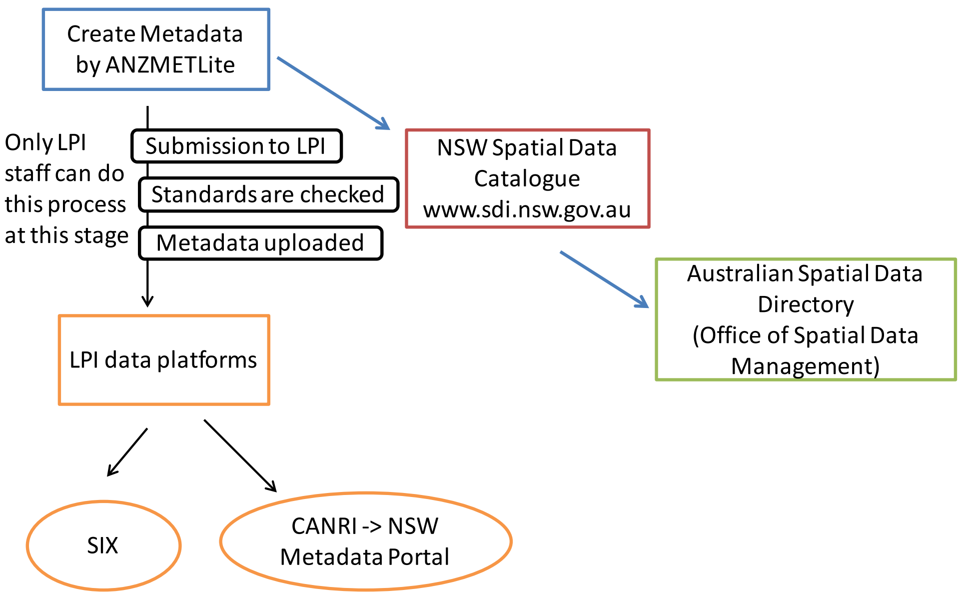



**Figure 6: Metadata upload workflow according to the NSW Natural Resource Data Directory**

**Table 5 : Summary of data or information type by custodian that was used in the current prototype of OIP**

| Data category | Custodian | Data Description |
|---|---|---|
| Water Quality | NSW Office of Water | Water Level & Discharge |
| | MHL/ OEH | Water level/ Tidal level |
| | OzCoast- State and local gov. | Historical Water quality |
| | NSW Fisheries/ Researchers | Historical Water quality |
| | Councils involved per LGA | Water quality (Physical, chemical & nutrients) |
| | NSW FA | Water quality (Temperature & Salinity) |
| | NSW FA | Harmful Phytoplankton |
| | Researchers- UoW | Water quality (Temp, Sal, pH, DO, Turb) |
| | DECCW-MER Monitoring | Water quality (Physical, chemical and nutrients) |
| | Researchers –ANU (PhD) | Water quality (Physical, chemical and nutrients) |
| | UoW/ SRCMA | Water Temperature |
| Catchment | Local council/ Sydney Water/ Shoalhaven Water | Sewage Treatment Plant s locations |
| | LPMA | Land use types |
| | LPMA | State Forest and National Parks |
| | SCC (*only available for Shoalhaven) | Flood gates location |
| | SCA | Dam |
| | LPMA | Acid Sulfate Soils |
| | SRCMA | Catchment Management work (stream bank; riverbank; re-vegetation; laneway; floodgate work; fencing; effluent) |
| | OEH | Estuary Drainage Catchment |
| Industry | NSW FA | Oyster harvest areas |
| | NSW FA | Oyster flesh biotoxin |
| | NSW FA | Bacteriological (water and oyster) |
| | NSW FA | Heavy metals in oysters |
| | NSW DPI Fisheries | Aquaculture leases |
| | NSW DPI Fisheries | OISAS priority leases |
| | UoW/ SRCMA (* not available in Camden) | Oyster performance |
| | Researchers – ANU, SU | Oyster performance |
| | Researchers – SU | Oyster Disease (QX and POMS) & water quality |
| | Hornsby Shire Council | |
| | Oyster Industry/ Oceanwatch/CMAs | Environmental Management Systems |
| Natural Resource | NSW DPI | Macrophytes |
| Climatic | BoM | Rainfall |
| | Climate Commission & BoM | Climate Change projections & statements |

## Accessing and processing data

Overall data custodians were willing to share data and information and contribute to the development of this project. There was diversity in the status and manageability of the different data sets. Most of the water quality datasets were organised in similar formats, and minor adjustments of columns and amalgamation of worksheets was required. In contrast GIS datasets were particularly poorly organised and, in some cases, interpretation was very difficult. A lot of communication with custodians and file exploration was required to identify where and what data was useful. In very few instances was data not permitted for graphical interpretation through the OIP, however there were instances where data had to be aggregated to overcome privacy issues. For instance catchment works undertaken by the SR CMA were aggregated in 5km$^2$ grids so that work undertaken could not be linked to a specific land owner.

Data was not made directly available through the OIP as there was not a system of legal process to address all of the concerns related to the release of data. This was not an obstacle for most of the objectives of the OIP, however in the future the availability of publicly funded data can be facilitated through Creative Commons licensing and this is described in a case study below. In addition, the required work effort to translate data to information through the OIP demonstrated the need for implementation of national standards of data management and storage in order to facilitate access to and use of data. Under the current practices, the long term viability of portals such as the OIP is difficult with a high demand of desktop labour to both discover data (see metadata above) and then to access and reformat the actual data resource. Available information is rarely streamlined according to national standard procedures for data management that already exist (Hook *et al.*, 2010). Standard systems for sourcing and categorising data effectively are common place in successful organisations, and provide information on strong performing areas and priority targets to develop. Local and state government agencies were poorly lacking in such system management, standards, and uptake of technology. Reasons for this have been demonstrated elsewhere and include barriers of limited financial, technical, and personnel capacities as well as legal issues (such as privacy) (Moon 2002). This contributes to a series of obstacles in the development of data portals or in the process of disseminating information. Unfortunately there is no agency mandate to amalgamate associated data sets from one location across agencies for maximum information access. This reinforces the need for a prototype such as the OIP to demonstrate the possibility of overcoming that process and mandate gap, and to demonstrate the knowledge gain from adequate data management, storage and processing.

## Data and metadata central repositories

Top down governance initiatives have led the way for establishing a set of data central repositories in order to manage and access national and state outputs from natural resource monitoring programs. A challenge for data portals with a top-down strategic initiative is to become relevant and accessible to small and medium user groups that make up the majority of stakeholders at the local level; for example local governments and industries like the oyster industry. Therefore it is important that bottom up approaches identify and take advantage of top-down strategies and structures to deliver information with local relevance. A requirement for this is the provision of tools and solutions to legislative challenges such as the sharing of spatial data, as well as logistical and infrastructural challenges of data management and storage facilities. This is a pre-requisite to progressing the concept of the OIP to a greater geographical scale and scope of information, and requires that the legislative conditions and framework are established and that data can be collected, stored and accessed.

In this project, streamlining of all data custodian data management and storage systems was not possible, however a process of the workflow required to deliver a water quality data set to a centrally stored and accessible repository is outlined including:

1) Metadata creation and storage
2) Identification of a central data repository suitable to maximizing discoverability and dissemination of data according the established national systems

3) Data formatting
4) Data licensing
5) Delivery to repository

**The process needed to be undertaken by the different data custodians involved in the management of such resources is outlined in (Figure 7). Currently such data is by default functionally confidential (**

Table 6), despite it being publicly funded and invested in for public good. This is primarily a legacy of the historical logistics of data collection and management, but also to a degree of uncertainty regarding the responsibilities, sensitivities and legal consequences of making data publicly available.

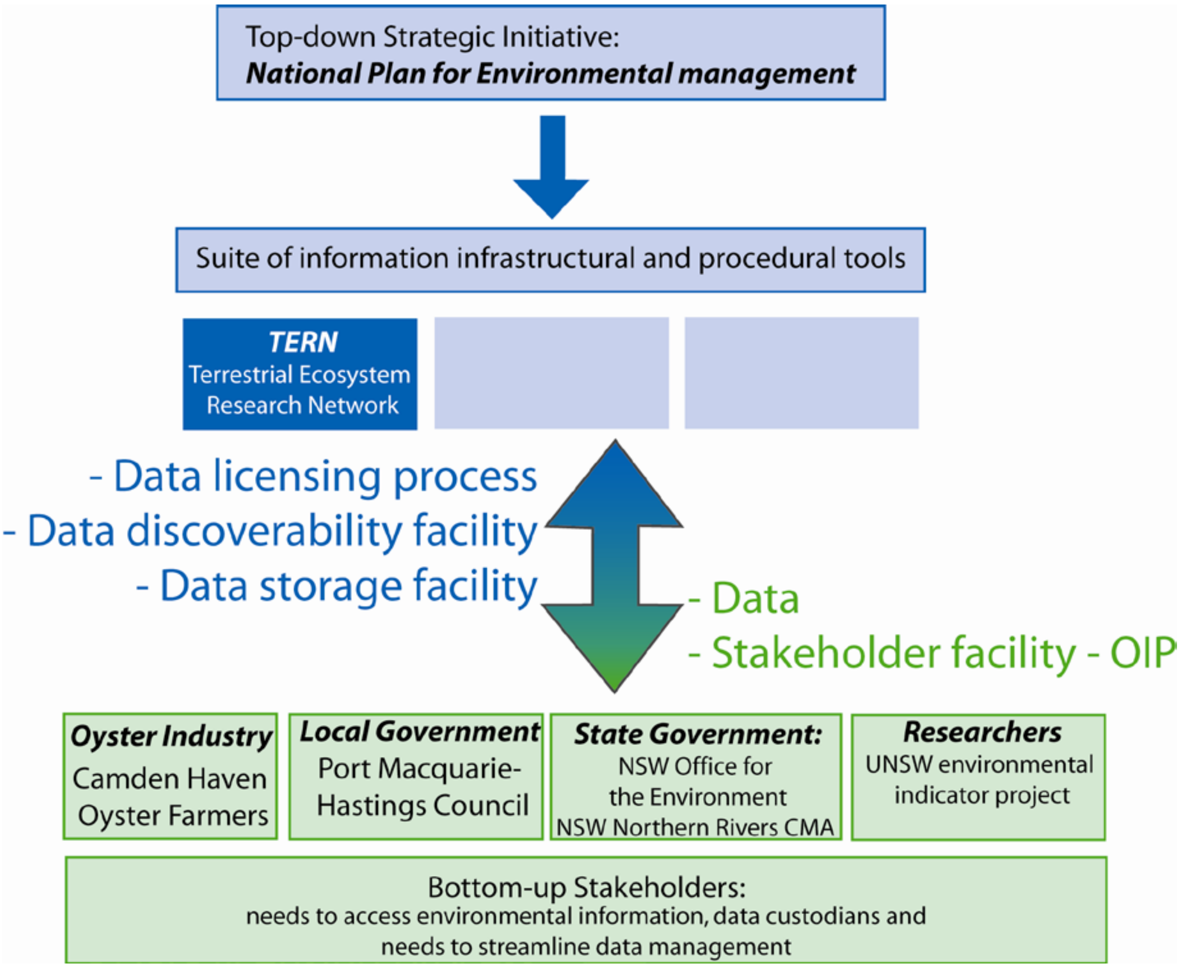



**Figure 7: The initiatives, needs and the gap issues that prevent effective access to data and information**

**Table 6. Functional Levels of data discoverability and accessibility**

| Functional levels of security | Meta-data discoverable | Licensed Data accessible |
|---|---|---|
| 1 Confidential | no | no |
| 2 Discoverable | yes | no |
| 3 Accessible | yes | yes |

Meta data creation and storage was undertaken by OIP researchers and the data custodians using the ANZMet Lite software (see above). This involved entering descriptors of the University of New England data set that was created for the Port Macquarie Hastings Council EcoHealth program; for example, number of sites, date of sampling, parameters of data (pH, temperature, salinity etc.). This metadata file (Metadata_PMHC_EcoHealth Program.pdf D8E1BB3E-5DB1-46FF-95EA-C8343A66AABF) can be viewed within the Oyster Information Portal at http://www.oysterinformationportal.net.au/mappetizer/Mappetizer_scale_2pmhc/scale2pmhc.html.

The Terrestrial Ecosystem Research Network (TERN - http://tern.org.au.html), and specifically its Australian Coastal Ecosystems Facility (ACEF - http://tern.org.au/Australian-Coastal-Ecosystems-pg17732.html, Figure 7) were identified as one of the current storage points that are relevant for storage of data and metadata. The objectives of TERN are to provide infrastructure that "connects ecosystem scientists and enables them to collect, contribute, store, share and integrate data across disciplines. Collectively this increases the capacity of the Australian ecosystem science community to advance science and contribute to effective management and sustainable use of our ecosystems". However the objectives extend to include data from local government monitoring programs and the like, as long as the conditions of broadly publicly accessible data through licensing can be achieved (TERN communication).

Licensing options for the data set were explored according to diverse Creative Common licensing (http://creativecommons.org.au/learn-more/licences) approaches that are being established for diverse types of marine community data. The TERN facility solution to Creative Commons Licensing is comprehensive and flexible, but still operates under the broad premise that data should be publicly available and useable. In addition, systems have been developed to identify data sets in a way similar to that achieved through peer-reviewed publications. This is in part achieved through the provision and identification of data sets and / or metadata with digital object identifier (DOI) codes. These codes are unique and can be used in the same way as journal citations.

By uploading a State government data set to a public data portal storage facility and by informing the steps involved in the process it is expected to generate significant interest among other data custodians to follow the initiative. Similarly, this whole OIP project has been described and become discoverable through the TERN Coastal Research facility (http://coastalresearch.csiro.au/?q=taxonomy/term/134).

## Oyster Information Portal Prototype

The main output of this project was the development of a proof of concept Oyster Information Portal (OIP). This tool has been embedded in the website www.oysterinformationportal.net.au. The website as a whole contains information about the project, oyster industry relevant information in the form of documents, reports, current events, climate related forecasts and projections and access to the actual data portal.

The OIP has been designed with a simple user interface to maximize inclusive use from industry to agency and policy levels. The current structure of the OIP has been delivered at two spatial scales. Scale 1 represents Australia as a whole to provide basic information across states and as a framework for the continued development of OIP into the future (i.e. including other oyster producing states) (**Error! Reference source not found.**). Scale 1 provides information on the types of oysters that are cultivated in each state, the authorities that manage or regulate different aspects of the industry, as well as the historic records of oyster production and value in each state. For NSW, Scale 1 also holds general information about the 4 Local Government Areas (LGA) and Oyster producing rivers that have being developed in detail for the project (Camden Haven, Hawkesbury; Shoalhaven and Pambula) (Figure 9).

Information for these regions includes links to councils, Natural Resource Management authorities, relevant sections of State of Catchment Reports, catchment features, oyster industry history and local oyster production. From the estuary information, Scale 2 can be accessed which contains the bulk of data sourced for the OIP in each of the four estuaries (and Figure 10). This scale contains graphical representation of data from sampling points that represent sites in most of the monitoring programs run by diverse agencies. Each estuary location differs slightly in content due to differences in monitoring programs and local context, but over to 20 custodian data sets are available at each estuary and include tens of thousands of data across points in each estuary. Thus the true power and knowledge encapsulated in the OIP is still to be developed but some case studies are included below to demonstrate that concept.

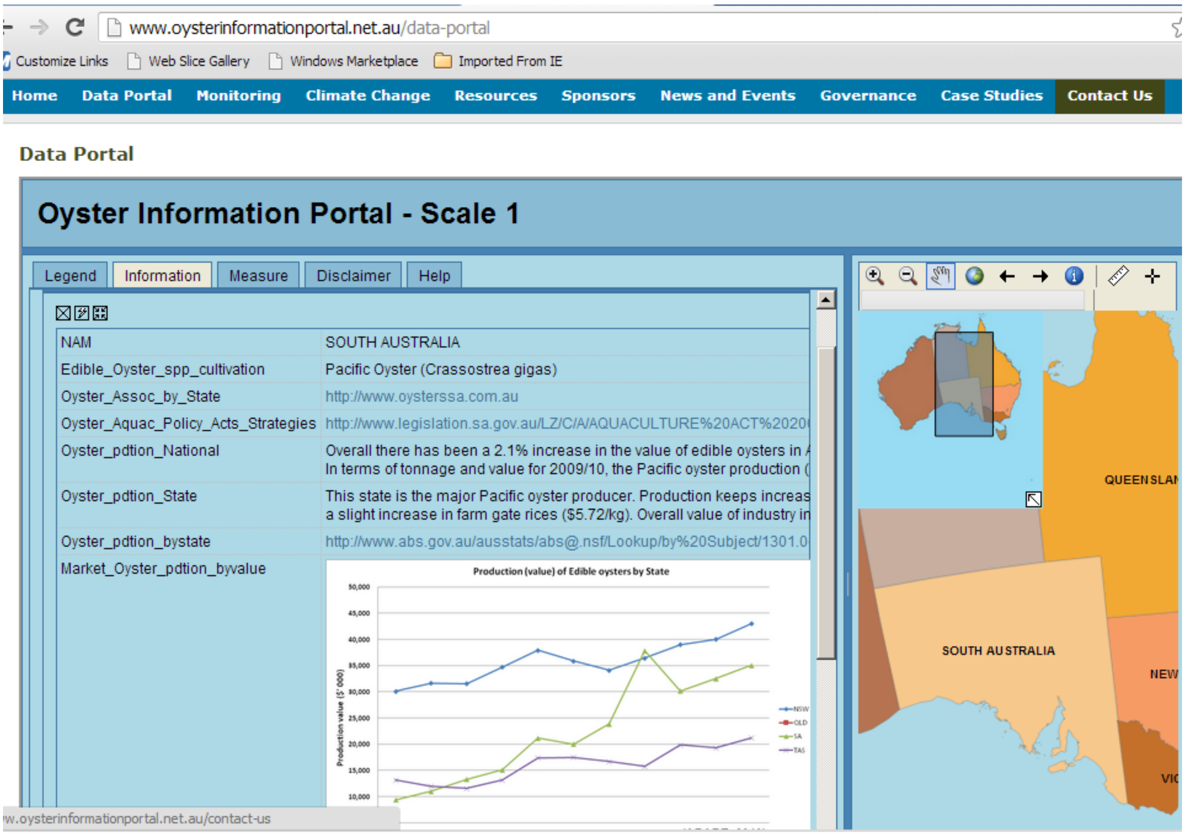



Figure 8. Screen capture of Scale 1 of the Oyster Information Portal

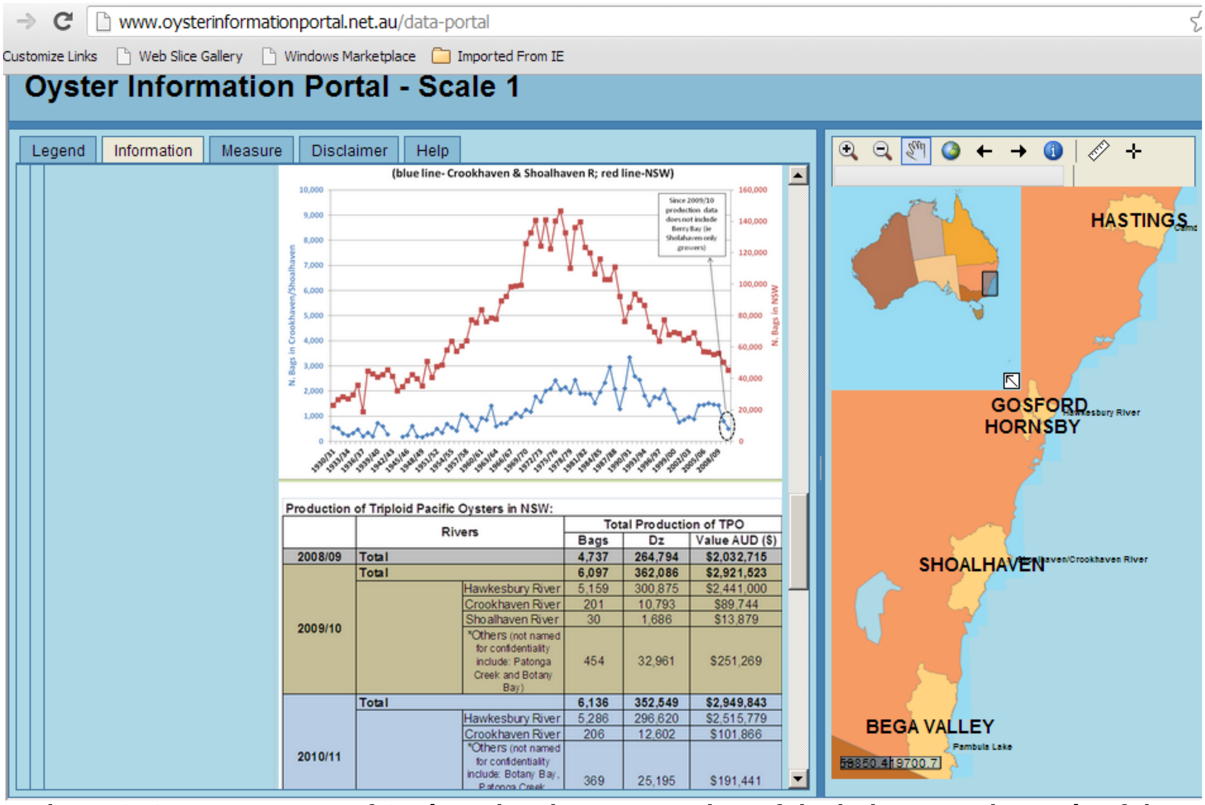



Figure 9. Screen capture of Scale 1 showing an overview of the industry at the scale of the estuary in the local government areas.

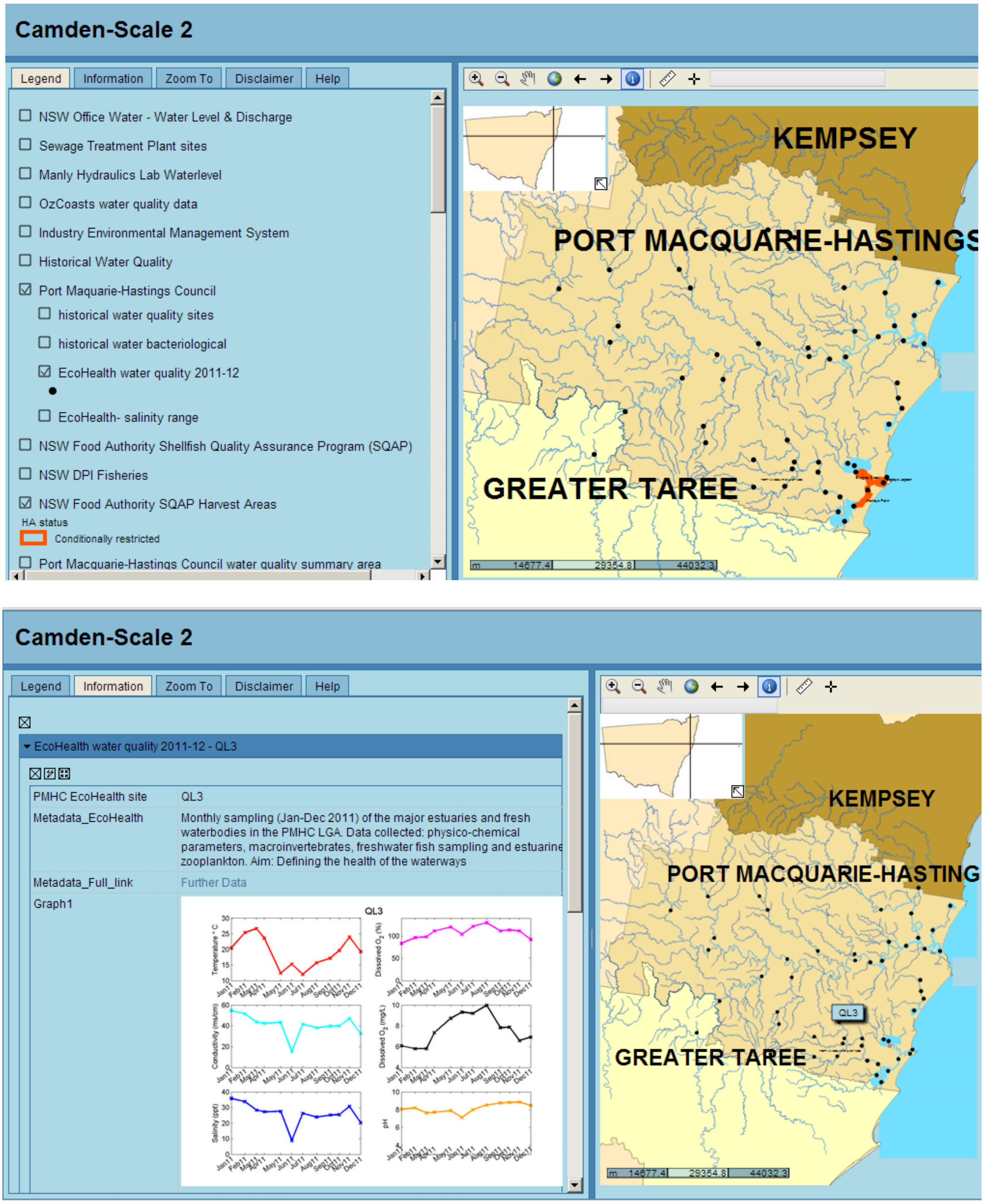



**Figure 10: Screen capture of Scale 2 for the Port Macquarie- Hastings area, including custodian linked monitoring sites and an example of site data for the Camden Haven**

## OIP users' feedback

Based on the feedback received from industry workshops, stakeholder meetings and recent online surveys, the OIP prototype received broad acceptance as a tool that will be able to assist the oyster industry in their future planning and adaptation to a changing environment. In particular, by accessing the information included in the portal, industry members can now understand environmental and catchment data relevant to oyster production. Industry members are able to foresee the use of the portal as a central repository for knowledge sharing that will assist them in continuing to develop the information and communication needs of the industry.

Feedback from the main users of the portal was gathered via face-to-face in industry workshops, online meetings with the steering committee, email communications with users and through an on-line survey (Figure 11). Users ranked the OIP data portal section as the most important source of information (Figure 12). The tab on climate change statements, Oyster Monitoring Program and forecast predicted by BoM, CSIRO and other research bodies were also used. In addition, users said that the portal was as expected or easy to use (Figure 13Figure 1), and that they would use the Scale 2 of the OIP, with specific site data and information, on a weekly to monthly basis (Figure 14).

In addition all user groups continued to rank water quality monitoring programs as their highest priority of information; consistent with the identified priorities at the outset of the project. Users also found the NSW Food Authority information of great use, including bacteriological, biotoxin, heavy metals and harmful algae information. Similar ranking was given to the water level information as well as the results from the oyster monitoring program (Figure 15).

Users were also asked to rank the objectives that were targeted through the development of the data portal (Figure 16). Overall the portal users considered that the OIP facilitates increased connection to environmental catchment data that is relevant to the oyster industry. Users also appreciated that the OIP provided a node of knowledge sharing and an information repository that will facilitate industry members and catchment managers to make practical and adaptive responses to current and future changes in environmental conditions.

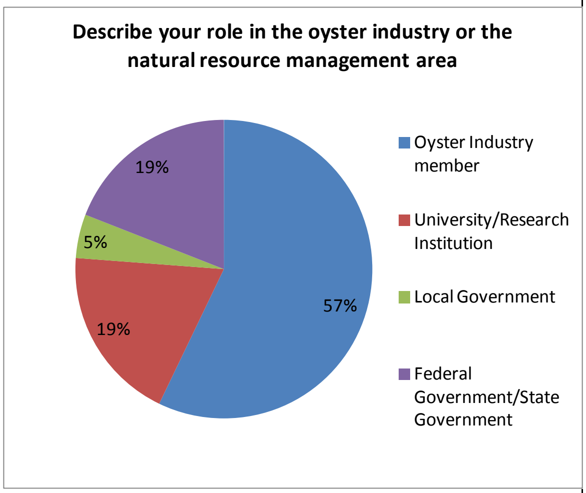



**Figure 11: Percentage of portal users that provided feedback through the online survey**

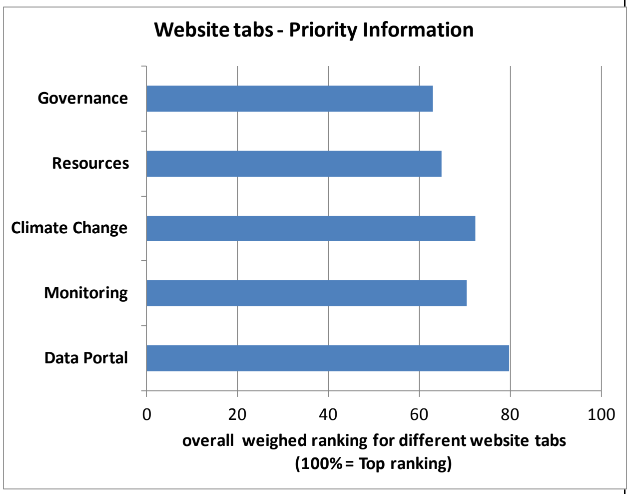



**Figure 12: Information priority presented in the OIP website**

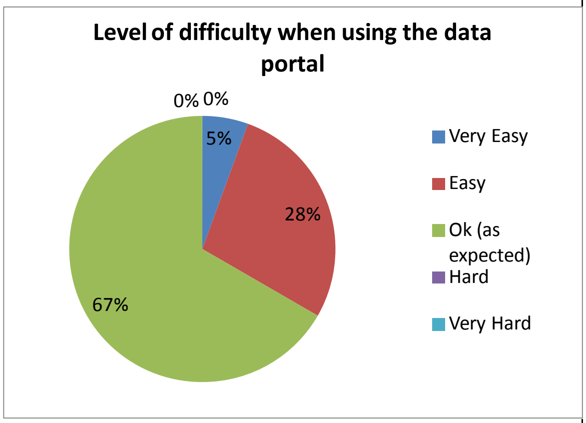



Figure 13: Scores from users in regards to the level of difficulty encountered when using the data portal

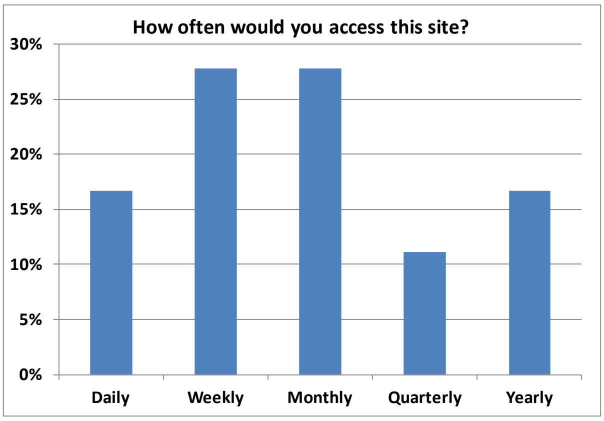



Figure 14: Frequency of anticipated use of the data portal

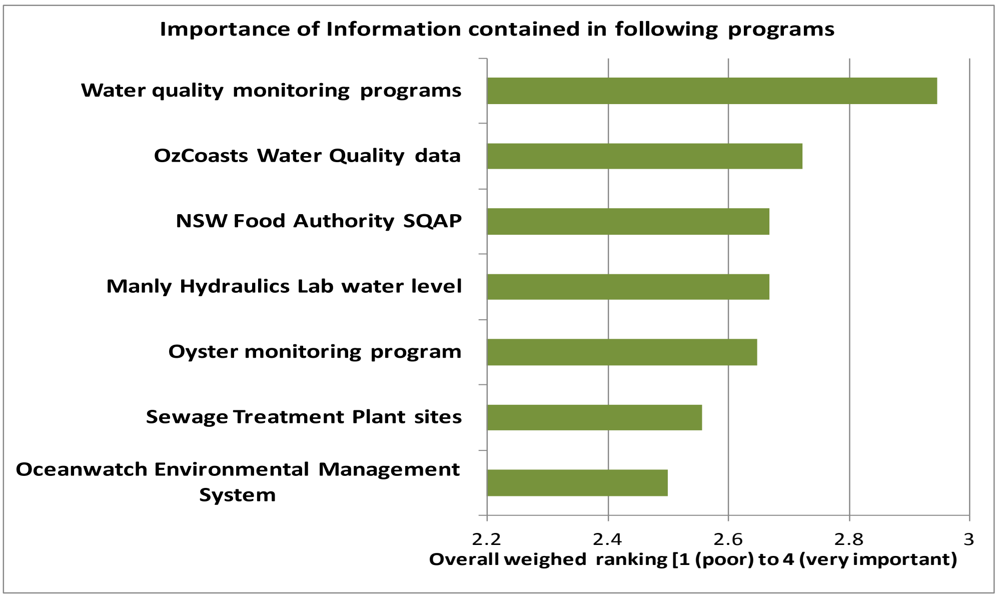



Figure 15: Priority information for the different layers of information contained in the OIP

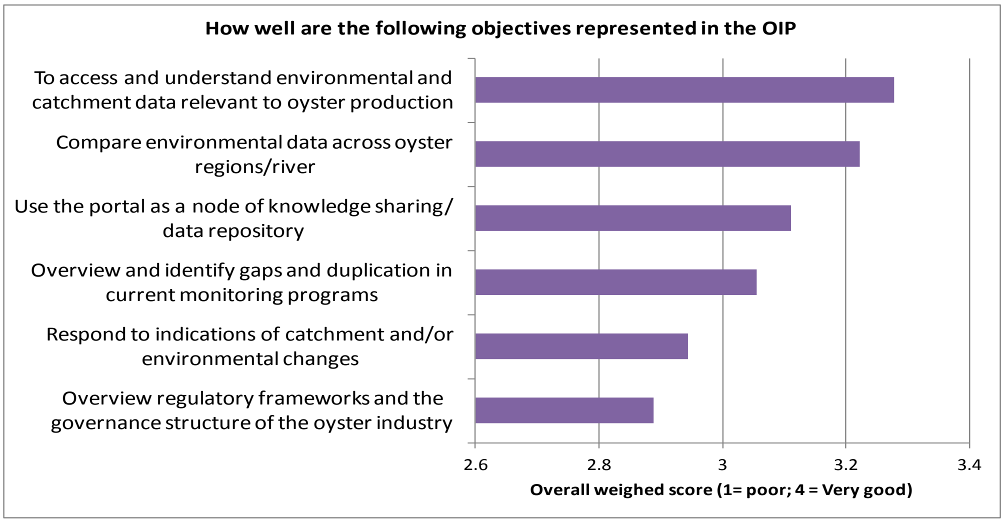



Figure 16: Users' feedback rating some of the objectives of the overall projectOIP as a monitoring tool – value adding to the investment in shellfish monitoring programs

# Case studies from analysis of data and information contained within the OIP

## Case Study: Identifying trends in the Clyde River Shellfish Quality Assurance program

Shellfish Quality Assurance Programs (SQAP) are a spatially and temporally extensive data collection programs, invested in by the oyster industries and state food safety authorities. The extent and value of this data is not well recognized amongst natural resource managers in other agency contexts; however it is often one of the most rigorous estuarine monitoring activities in terms of the number of sampling sites, sampling frequency as well as the extent of parameters that include species level taxonomy of phytoplankton, water quality and pathogenic microorganisms. In NSW and most states, this data is currently only used for real time responses human health risks by the consumption of contaminated oysters. There are trigger levels of contamination or harmful algae blooms that close an oyster harvest area to harvest for a period of time. One of the key concerns in these shellfish monitoring programs is toxic shellfish poisoning from harmful phytoplankton toxins consumed by the oysters.

Phytoplankton are of importance to the oyster industry and estuarine condition in a multitude of ways beyond food safety:

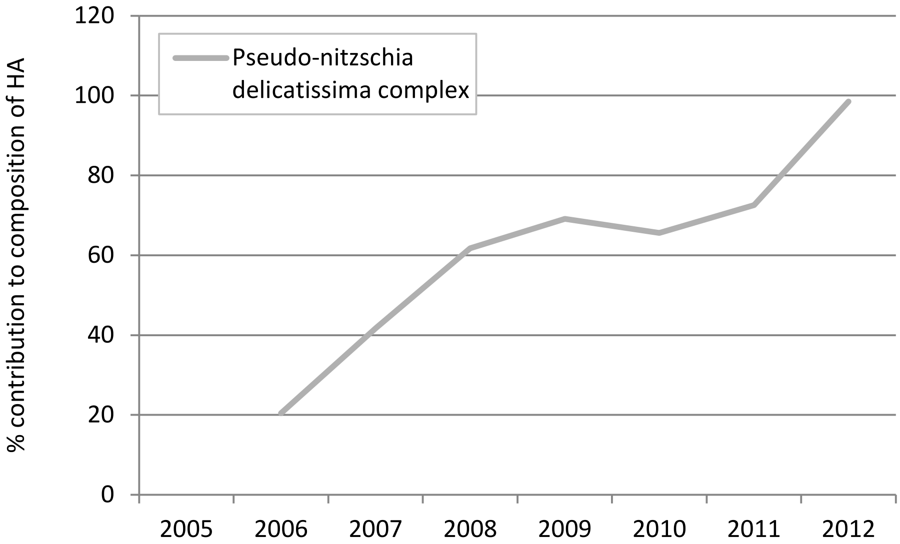
- Phytoplankton deliver the food and energy required by oysters; thus driving productivity
- Phytoplankton absorb and alter the types of nutrients available in estuaries, which dictates the trajectory of trophic composition and thus the feed source of oysters
- Phytoplankton respond rapidly to specific environmental queues (e.g. sunlight, temperature and nutrient availability) and as such, less desirable species have the potential to bloom and close shellfish industries due to toxic health effects on consumers (e.g. *Alexandrium* spp.) or less frequently detrimental effects on the health of the oysters themselves.

Thus phytoplankton are thought to be one of the first indicators of change in estuarine conditions whether it be from the catchment of from longer term climatic effects (Tester 1994; Hallegraff 2010).

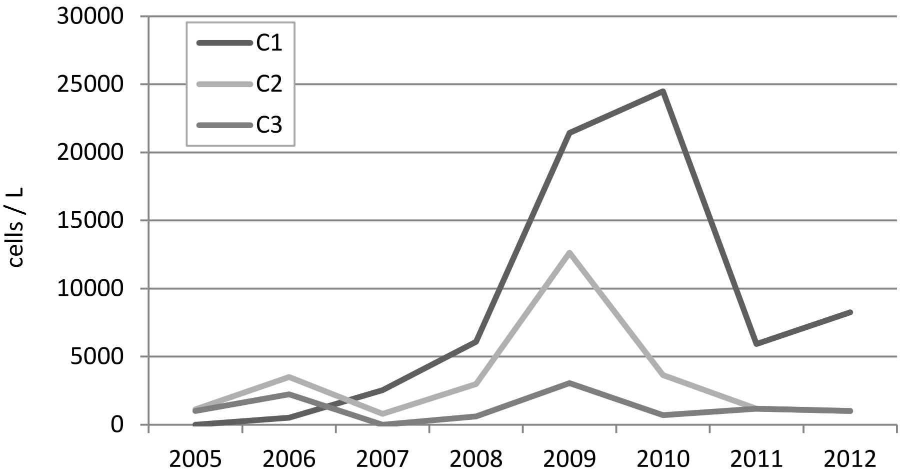
In NSW, the SQAP typically include water sampling for phytoplankton as frequently as fortnightly schedules depending on the location, and throughout the year delivering detailed data on species level resolution of harmful algae. Despite this data being abundant and regular and quality controlled under through training and authorisation procedures, it has, until recently, only been utilised towards managing the health risks to humans from seafood without any long term analysis of the data. Ajani et al. (2012) analysed extensive data sets of harmful algal bloom (HAB) species data in a rigorous evaluation of spatial and temporal patterns, including 45 taxa from 31 estuaries in NSW. This analysis showed evidence for discrete harmful microalgae communities from the upper reaches of estuaries compared to the lower estuary. This suggests that factors such as salinity may be key drivers of microalgae diversity; thus any climatic shifts that result in altered patterns of precipitation could trigger shifts in HAB distribution. In addition there was an increase in HAB species abundance with increasing latitude (decreased water temperature), suggesting that increased water temperatures may be linked to reduced risk of harmful algal blooms. However other factors are also of influence and it was found that modified catchments and low turnover estuaries maintained a higher abundance of HABs for longer, suggesting that not all rivers require the same amount of time to recover from HAB events.

Considering that the non-harmful algae are an important food source for the industry, and that changes to climate are predicted to affect the composition of primary producers such as microalgae, it seems pertinent that the monitoring program data is analysed further for trends in time and space for both oyster industry benefits, risks as well as for natural resource managers. South Eastern Australia is considered to be a hot spot for climate change effects of a rise in sea surface temperature, which can also influence estuarine temperature. Tester (1994) predicted in that shifts in the dominance of certain species of phytoplankton would be a consequence of climate change. Thus if future algal blooms are to comprise an increased dominance of harmful phytoplankton, then this has serious consequences for the oyster industry.

One finding from the analysis of Shellfish Quality Assurance Program data within the Clyde River, NSW, showed that the composition of Harmful Algae shifted primarily across seasons within sites, and that this was related to the abundance of species rather than the composition of phytoplankton assemblages. Thus composition was relatively consistent. However further examination of longer term temporal and spatial patterns revealed a consistent compositional trend over the eight years of harmful algal sampling across all sites. The *Pseudo-nitzschia delicatissima* complex was identified as the species that was driving this trend (Figure 17). The dominance of this taxonomic complex to the overall harmful algae composition increased steadily and consistently during this period, although the total abundance varied across all three sites in the Clyde River. Identification of such trends does not conclusively demonstrate a functional shift nor an effect of climate or catchment change, however it is an example of the emerging trends and the importance of long term monitoring data as the Total *Pseudo-nitzschia*' group has been identified as the taxon contributing most to harmful algae excedances in some of the NSW estuaries (Ajani *et al.*, 2012; Trainer *et al.*, 2012).




(a)




(b)

**Figure 17: (a) Percentage contribution of the *Pseudo-nitzschia delicatissima* complex to the composition of harmful microalgae in the Clyde River for all three sampling sites across 8 years, (b) the abundance of *Pseudo-nitzschia delicatissima* complex (cells / L) at three sampling sites in the Clyde River over 8 years.**

## Case Study - Oyster performance based on environmental conditions

Oyster monitoring programs, as distinct from food safety programs, are rare in Australia and across the world. Recently an innovative Oyster Monitoring Program (OMP) was established in partnership with NSW oyster growers on the south coast, the Southern Rivers Catchment Management Authority (SRCMA) and researchers from the Shoalhaven Marine and Freshwater Centre (SMFC) at the University of Wollongong. This program monitors and quantifies oyster performance (i.e. shell growth) and oyster mortalities over time and from different leases and growing areas using commercial oyster graders. The need for the OMP was largely driven by an industry desire to improve coastal & estuarine monitoring programs in order to better understand oyster and ecosystem performances (Leith and Haward, 2010).

Farmers are aware of many of the relationship between the environment and oyster lease productivity. However, a lack of integration between bio-physical knowledge and industry knowledge currently constrains effective management of the oyster industry. As such, farmers are often left with unanswered questions or anecdotal information to account for the causes of changes in productivity from year to year. Preliminary results corresponding to the first year of monitoring in the NSW OMP are summarized in this section and also in a the conference proceedings submitted to the 2013 NSW Coastal Conference (Nash and Rubio, 2012). Further information on the monitoring program can be sought from http://www.oysterinformationportal.net.au/oyster-monitoring-program .

Such information can be used to characterize growing areas within selected estuaries, quantify changes in oyster performance based on environmental conditions and to refine industry technology and management. In addition sustained monitoring can establish a reference from which changes or unusual events (i.e. high mortalities, extreme changes in water conditions) can be detected and linked to potential causative factors.

Since May 2011, three estuary-wide trials were established in the Southern Rivers region; Shoalhaven River, Merimbula Lake and Pambula Lake. Currently running for 18 months, monitoring has expanded in scope by more than 200% to increase the number of oyster areas participating in the program to a total of five estuaries. The OMP tracks the performance of Sydney Rock Oysters (SRO) batches graded to a similar size (oyster length) and that are cultivated in different growing areas within a river or using different cultivation methods. Oyster performance data of growth and mortalities was collected every 2 months.

After a year of monitoring emerging patterns were observed across rivers and at specific locations. For example cumulative mortalities of SRO in the Shoalhaven River (average 30%±11) were higher than both in Pambula (average 18%±4) and Merimbula (average 14%±2) after the first year of monitoring (Figure 18). However sustained monitoring is required to strengthen the validity of these patterns at specific locations or unusual conditions.

Effects of temperature and salinity levels on feeding rates of oysters have been established in other studies (see review by Shumway, 2011). For example, existing literature reports that higher growth and filtration rates are positively correlated with temperature within a threshold (Cranford *et al.*, 2011). Thus preliminary relationships linking growth and mortality patterns to these environmental parameters were explored using OMP results and available environmental data. Environmental data was sourced from the industry Shellfish Quality Assurance Program that includes the most frequent environmental data. In addition, the local council managing the health of the waterways also monitors these parameters.

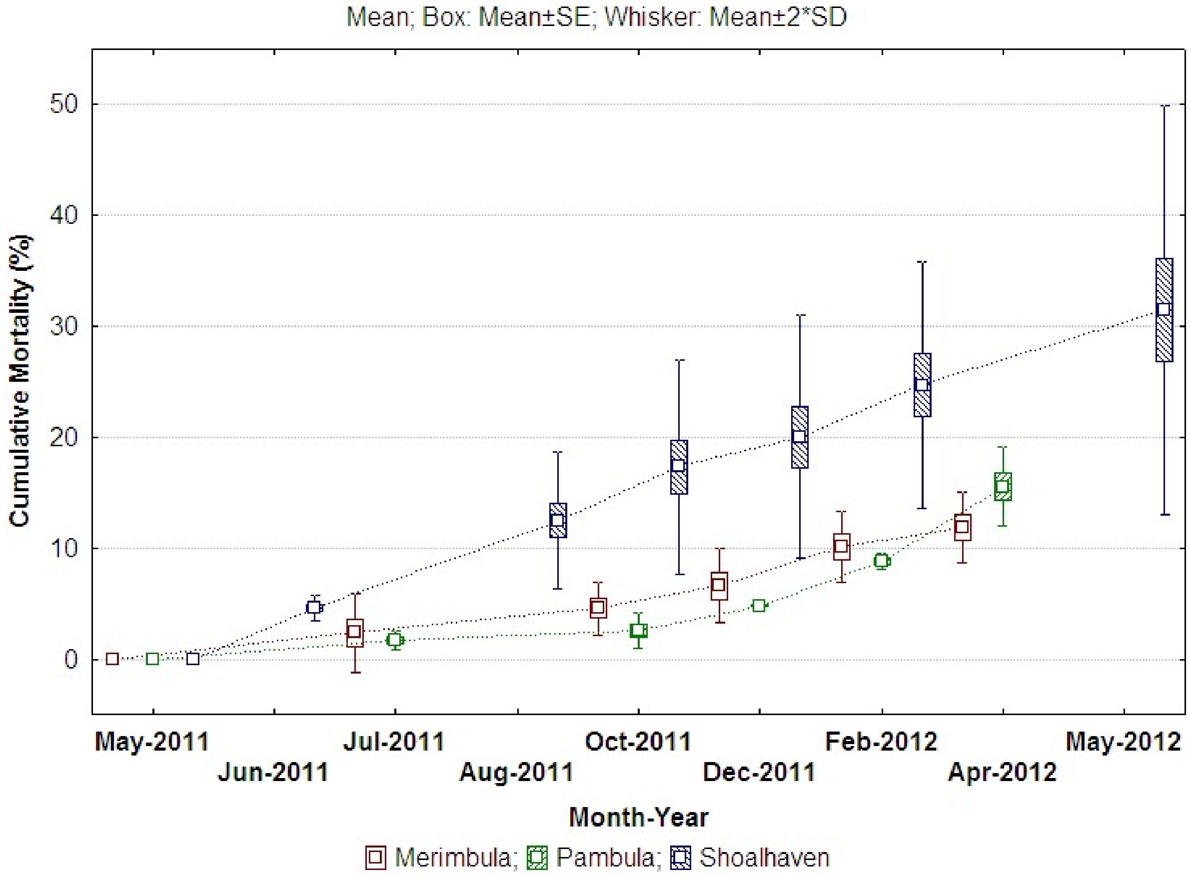



**Figure 18. Cumulative mortality percentages for Sydney Rock Oyster cohorts at Merimbula Lake (red boxplots); Pambula Lake (green boxplots) and Shoalhaven River (blue boxplots).**

Preliminary relationships showed that water temperature was positively correlated with oyster growth in all three rivers. With this preliminary data there is inadequate power to deliver statistical significance ($r = 0.4496$, $p = 0.3711$; $r^2 = 0.2021$), however demonstrating clear and consistent trends in productivity over longer time frames and across locations will potentially provide for adaptive responses by the industry to temperature patterns, optimising productivity and reducing risks for mortality.

In Merimbula and Pambula lakes during winter, water temperature at the entrance end of the lake was slightly warmer (by 1-2ºC) than in the middle of the lake. This resulted in slightly higher SRO growth near the entrance compared to the oysters cultivated further upstream (Figure 19 & Figure 20). Water temperature in the middle of the lake during winter reached on averaged 11ºC (Rubio, 2008). The reverse scenario occurred during summer when upstream water temperature increased to a few degrees warmer than water towards the entrance of the lake. Hence SRO growth was faster near the entrance of the lake (3-4mm advantage in shell growth). These findings suggest that shifting oysters across lake locations could deliver an advantage of up to 5% overall shell growth. This pattern was observed at both Merimbula (Figure 21) and Pambula Lakes.

No relationships were detected between growth and salinity, or mortality and water temperature or salinity. The prevailing wet conditions over the 12 month monitoring period may have compromised the detection of any relationships due to consistently low salinities. Extended analysis of monitoring data over future years and comparison with growth and mortality will provide increased reliability of these relationships. In addition, improved frequency and spatial extent of environmental data will also increase the sensitivity of detecting influencing factors on oyster growth and performance.

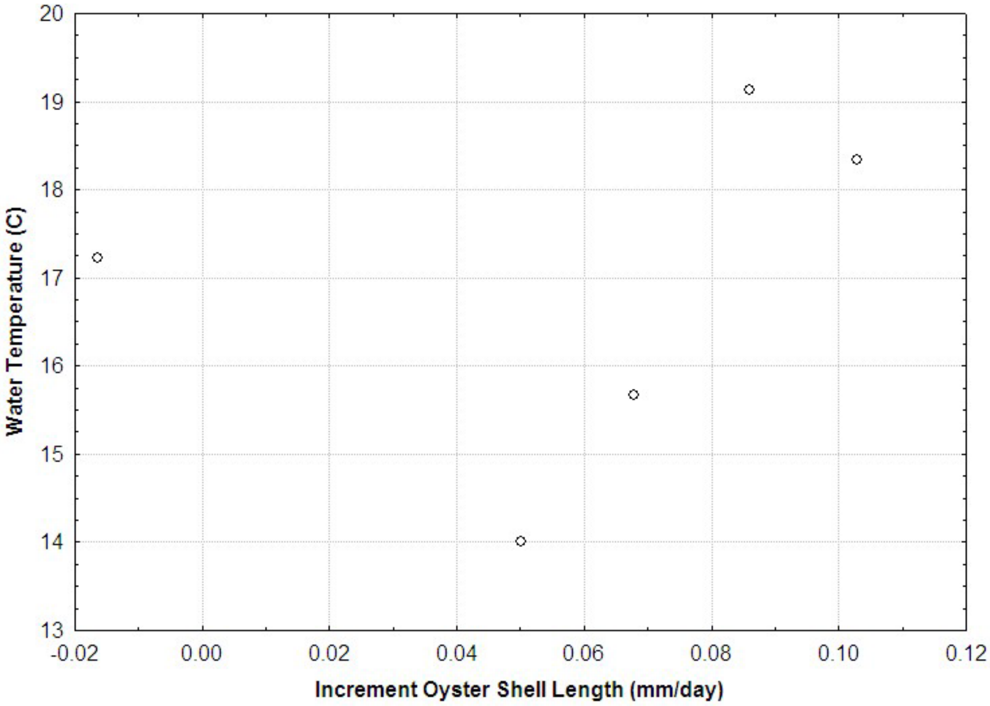



**Figure 19. Preliminary data demonstrating average oyster shell growth per day in relation to water temperature at the entrance of Lake Merimbula. This positive correlation requires additional data to control for the co-variant of oyster size and for additional power.**

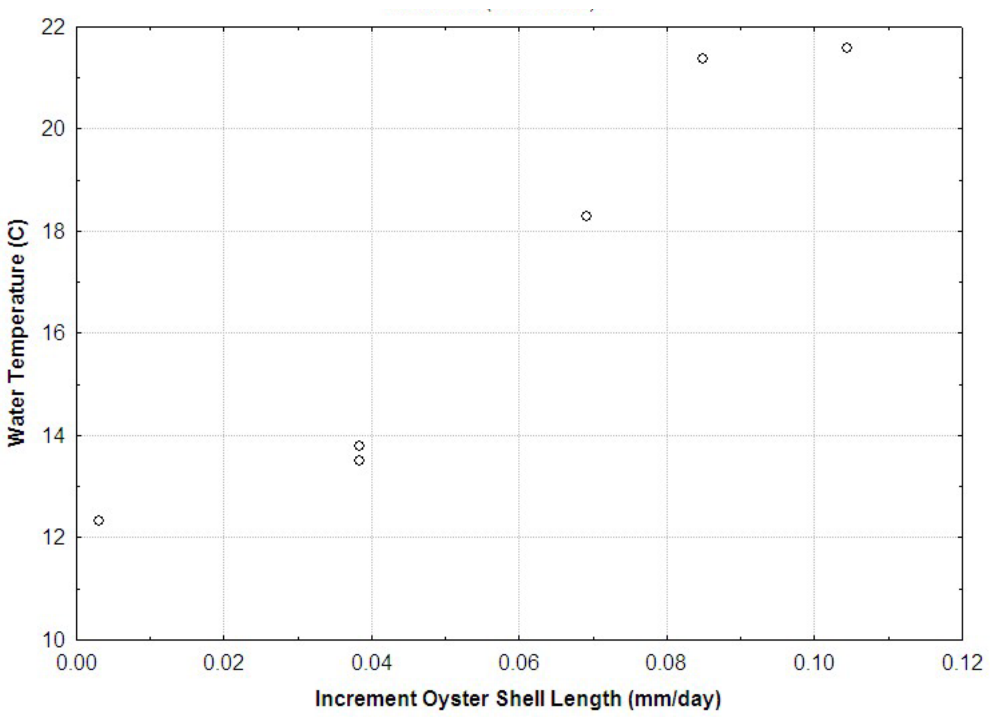



**Figure 20. Preliminary data demonstrating average oyster shell growth per day in relation to water temperature in the mid-lake section of Lake Merimbula. This positive correlation requires additional data to control for the co-variant of oyster size and for additional power.**

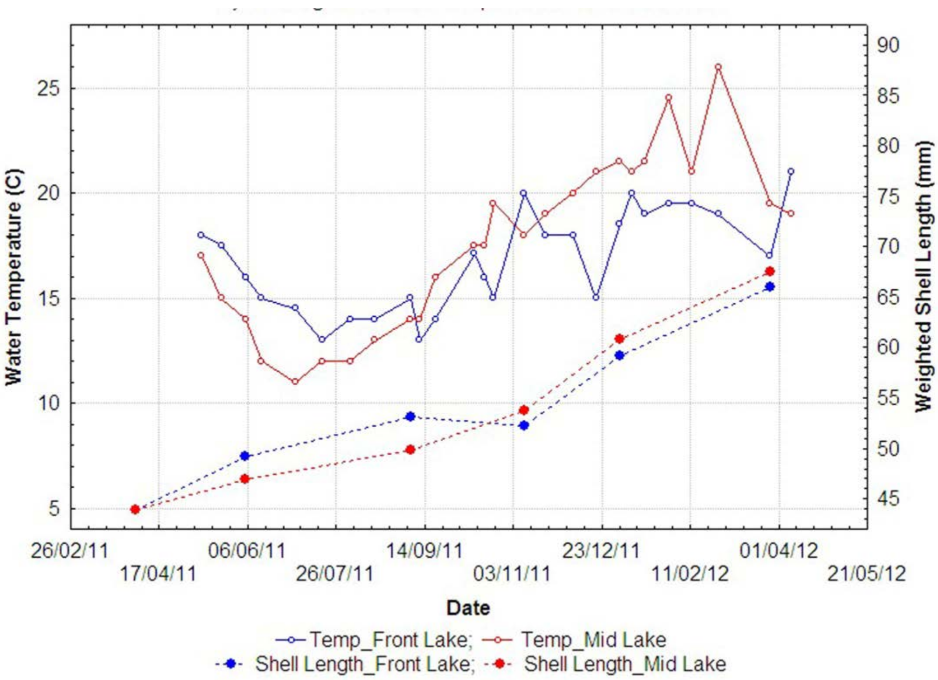



**Figure 21: Relationship between water temperature (left axis) and weighted average shell length (right axis) for Sydney Rock Oysters in the two locations in Merimbula Lake between May 2011 and May 2012**

A range of other environmental parameters such as chlorophyll-a (a proxy for calculating available food for oysters or phytoplankton biomass), suspended organic matter and dissolved oxygen are also known to influence oyster performance but are not pursued here. The information sourced from the OMP and its integration with information contained in the OIP will facilitate growers in selecting cultivation areas, seasonal management, cultivation techniques and adaptation to changing environmental conditions. Through increased monitoring effort and a greater understanding of the drivers that affect oyster performance , the oyster industry will be in a better position to respond to unexpected events and to develop more diverse adaptation options (Leith and Haward, 2010).

## Case Study: Oyster Genetic Resource Review – risks and hidden opportunities for increased resilience and adaptation to change

The industry identified that disease and seedstock availability were priority issues for them. This has also been identified by the NSW Fisheries as important and is indeed the focus of their efforts in strengthening the oyster industry, but also in preparing it for resilience and adaptability to climate change. Thus as for the salmon industry, where good genetic management and selective breeding programs have been critical to its success but also in its adaptability to different climates, within certain limitations, a better understanding of the genetic resource use and availability of new genetic resources was important in this study.

This review in its complete form has been submitted to the journal Reviews in Aquaculture (Kirkendale et al. (under review)) and aligns the history of oyster production in Australia in a global context. Here, and without suggesting any single cause of reduced productivity in aquaculture, we summarize the full review in terms of the genetic resources of oysters as a key vulnerability of the Australian Oyster industry, especially in light of catchment and climate change. However we also identify that there exists untapped genetic diversity that presents an opportunity for improved resilience and adaptive capacity for the industry.

Some investigations have explored reasons behind the devastation of *Saccostrea glomerata* aquaculture stocks through disease in Australia (e.g. Summerhaye et al. 2009). There is evidence to suggest that mortality events are in part linked to reduced genetic resilience, as the persistence of sizable wild populations of *S. glomerata* were observed in the Hawkesbury River, NSW, while aquaculture populations were wiped out by QX disease (Nell 2001). It is also probable, as Summerhayes et al. (2009) suggest, that oyster mortality in aquaculture will reflect farming stressors such as high stocking densities and reduced water flow that encourage conditions for QX disease to proliferate. However as also demonstrated in the Georges River, with the collapse of wild populations as well, farming management cannot be the sole contributing factor. Further confounding factors in eastern Australian estuaries include, increased host (oyster) abundance, rapid coastal development and the associated impact on water quality.

Summerhayes et al. (2009) suggest that wild populations in some estuaries may have evolved disease resistance to natal estuarine conditions; while cultured oysters reared from imported spat are not well adapted to survive in certain estuaries. A legacy of “highway farming” (Nell 2001) and extensive redistribution of genetic resources across NSW provides a very poor baseline upon which to measure genetic species populations that may be more or less susceptible to specific diseases. Thus the evidence in support of a single causative factor for oyster stock mortalities does not exists and it must be assumed that the environment, farm management practices and genetic limitations are the collective contributors to mortality events.

Therefore it is paramount to strengthen the industry in a three pronged approach through improved catchment and industry management practices as well as harnessing and managing the genetic diversity within species. The importance of characterizing and managing genetic resources both across species and within species for aquaculture cannot be overstated - this is the necessary foundation for any genetic improvement of cultured stock (Guo 2009). “Stock taking” of germ plasm diversity (Gaffney 2006) is essentially surveying genetic diversity across spatio-temporal scales to characterize inter and/or intraspecific genetic diversity of a given taxon. Genetic surveys from wide geographic regions, including extremes of range as well as habitat types and perhaps through time or seasons, are required to characterize what genetic diversity exists in a given population. One application of such data is that it permits you to enter into selective breeding work with a clear and comprehensive understanding of the diversity available to maintain adaptable stock and realize the improved yields (Hedgecock 2011). Although and perhaps because genetic diversity is so fundamental, it is has been overlooked or considered assumed knowledge in many cases.

Currently there are three genera of commercially important species in the edible oyster family Ostreidae: *Saccostrea* Dollfus & Dautzenberg, 1920, *Ostrea* Linnaeus, 1758 and *Crassostrea* Sacco,

1897. Numbers vary but approximately 40 or so species are recognized today across these three genera (Torigoe 2004). Nineteen species of true oysters (Ostreidae) call Australia home with this diversity distributed across nine genera and 3 subfamilies (Figure 23). Of this diversity, only a fraction are commercially important and these are: *Saccostrea cucullata glomerata, Saccostrea cucullata cucullata* (cultivated in India but unknown if cultivated in Australia), *Ostrea angasi/edulis* and *Crassostrea gigas*. Although not all species are grown in each state, it is these four species that represent commercially or potentially important species across all Australian states. For example, in NSW *S. glomerata*, *O. angasi* and *C. gigas* are grown in a $40+M industry while *C. gigas* in the other states contribute to the $90M Australian edible oyster industry; however production of *O. angasi* is still very low in relation to the other two species.

The oyster industry in Australia relies in part on spat sourced from wild recruits and in part from hatchery production. However hatchery production has anecdotally been sporadic and unreliable, especially for the Sydney Rock Oyster in NSW. This has had an effect of increasing reliance on wild spat in recent years, and hatchery spat now only contributes to 16% of the value of spat produced in NSW (Figure 22). Trade of spat across estuaries in NSW will have contributed to the transfer of genetic material across the state over the last century, much of which is poorly understood in part due to a lack of tracking or limitations to known population diversity of cultivated oyster species.

Adaptation to climate change for this industry will rely to a large degree on improvements in the availability of spat, and also the availability of diverse family lines of spat suited to local conditions. This requires the establishment of rigorous selective breeding programs which have been the backbone of most industrialised crops as well as aquaculture species such as salmon. Gjedrem et al (2012) identified 3 selective breeding programs for oysters globally with an average of 48 family lines per program. Considering that the oyster industry production is three times that of the salmon industry, which has 18 global breeding programs with 100's of families per program, it is clear that the opportunity to strengthen the oyster industry through selective breeding approaches has been overlooked. The following sections of this review summarizes the scope of current knowledge on the state of wild genetic diversity, selective breeding diversity as well as environmental implications of genetic diversity for the three main taxa of cultivated oysters in Australia.

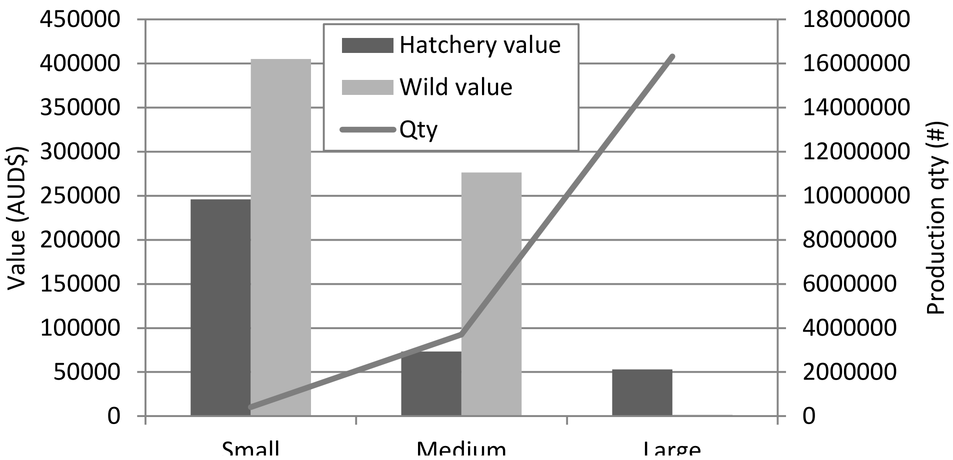



**Figure 22. The value of hatchery and wild sourced spat sold in NSW and the quantity of the spat produced across the size ranges small, medium and large.**

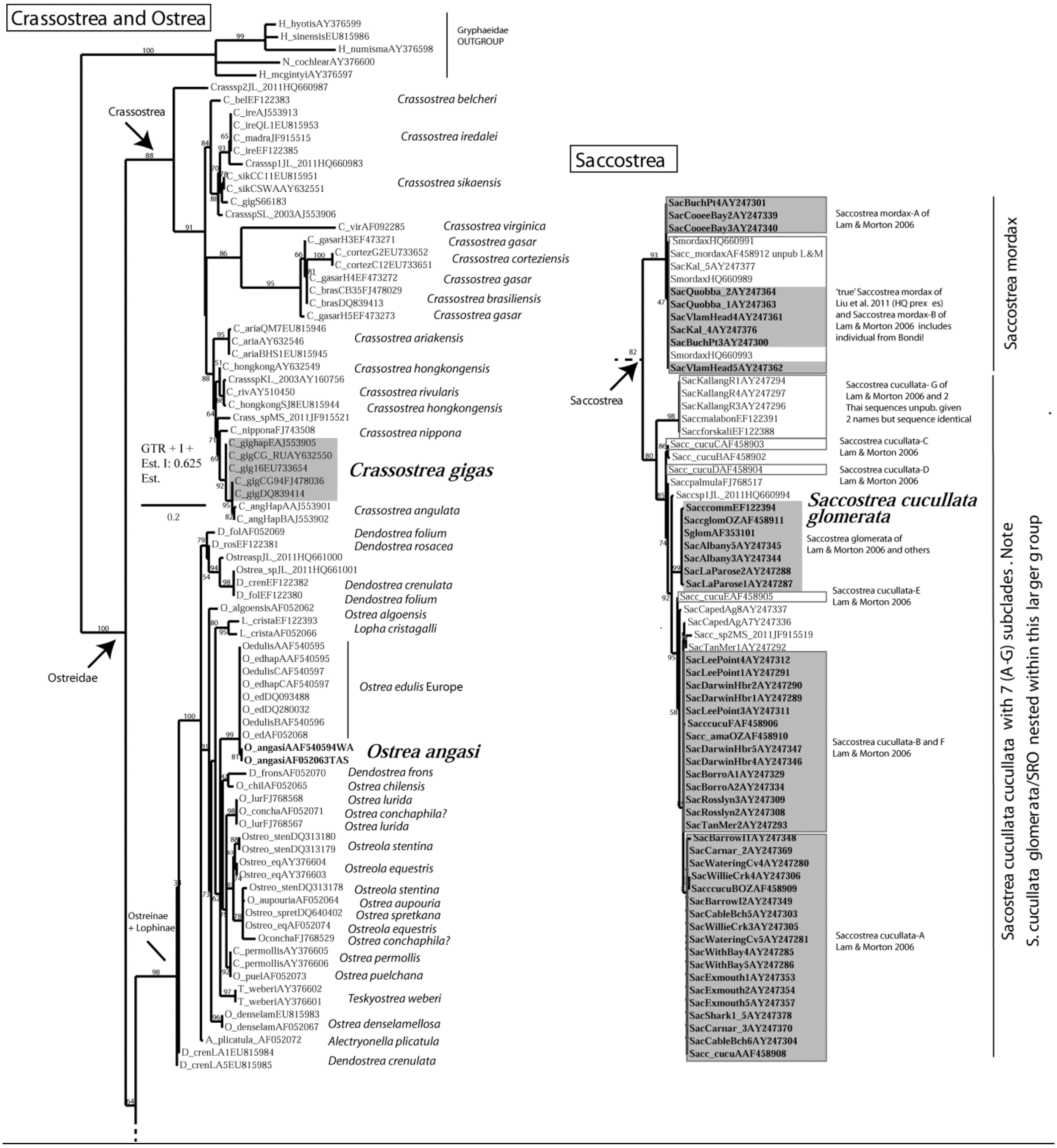



**Figure 23. 16S mtDNA ML phylogeny of ostreid relationships. All data from GenBank where identifications were tentatively followed but problems are apparent. Australian sequences are blocked in grey. Bold taxa represent species of commercial importance in Australia.**

## *Saccostrea* species

A synthesis of the diverse current databases and published distributions of these key taxa of *Saccostrea* spp. illustrates the current lack of consensus as well as inconsistent taxonomy (

Table 7), however an updated concept of species distributions is provided here (Figure 24).

**Table 7. A synthesis of diverse information regarding the taxonomy of commercially important *Saccostrea* in Australia from biological databases. *Valid names* are from Torigoe 2004, Huber 2010).**

| WORMS | OzCam | Other | valid names Taxonomy | Common vernacular |
|---|---|---|---|---|
| *S. echinata* | *Striostrea mytiloides* | *Ostrea mytiloides* | *Saccostrea echinata* | Black Lipped Oyster |
| *S. cucullata* | *S. cucullata* | *S. forskalii* | *Saccostrea cucullata cucullata* | Milky Oyster |
| *S. glomerata* | *S. glomerata* | *S. commercialis* | *Saccostrea cucullata glomerata* | Sydney Rock Oyster |
| Not recognised | Not recognised | *S. mordax* | *Saccostrea mordax* | Biting Oyster |

NB: Physical examination of biodiversity database voucher specimens was not undertaken and our interpretations are necessarily provisional.

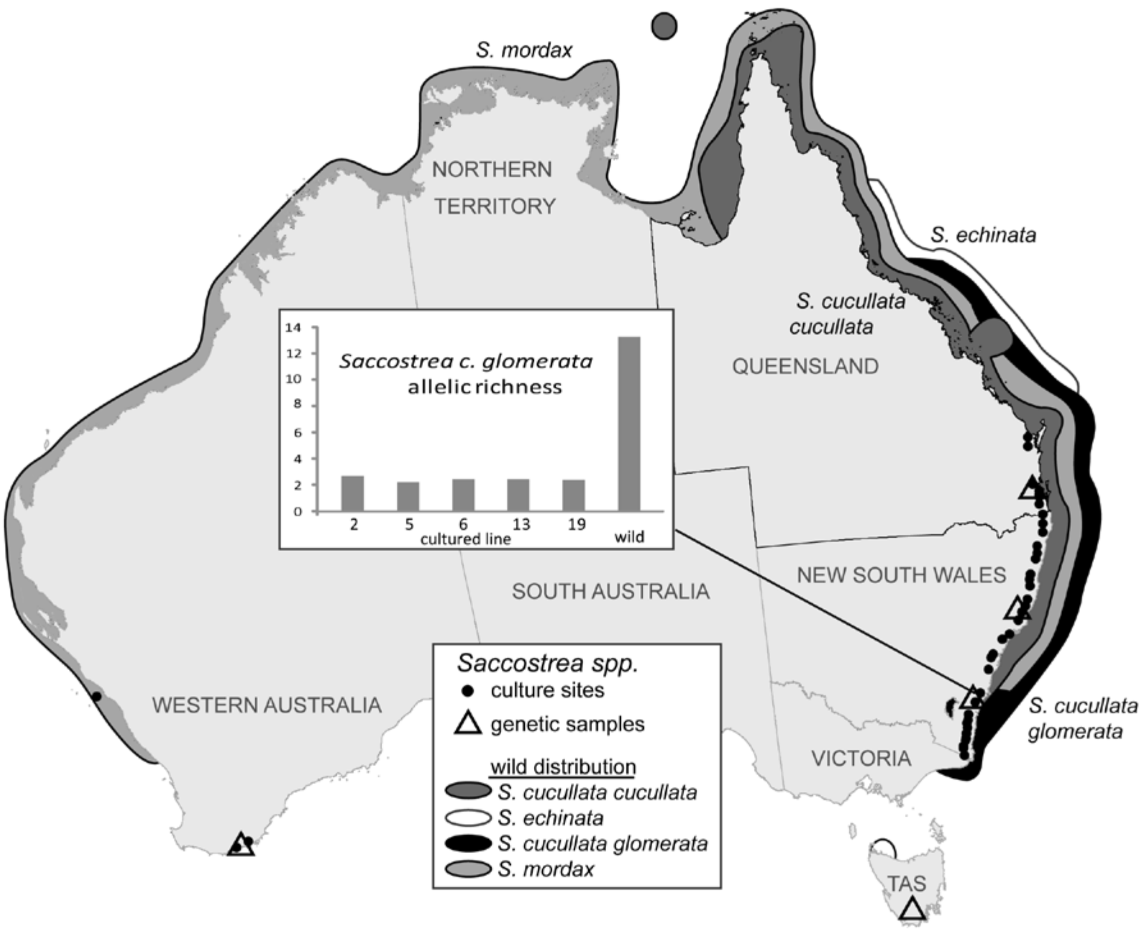



**Figure 24. Current estimated distributions of *Saccostrea* spp. in Australia as sourced from the records of the Australian Museum, (OZCAM 2012), (WORMS 2012), Natural History Museum of London and Western Australian Museum Records (as reviewed by Lam & Morton 2006).**

### ***Crassostrea gigas***

*Crassostrea gigas* is commonly known as the Pacific Oyster (PO and also triploid PO (TPO)). This is a large and relatively fast growing oyster native to Japan, but with a worldwide naturalized distribution in China, Korea, Australia, New Zealand, North America and Europe with a long history of translocations and introductions as described above. The introduced *C. gigas* is well established as a productive oyster industry in the southern states of Tasmania and South Australia since the mid 1900's where native species of *Saccostrea* were not existent (but see below for *Ostrea*). The first genetic resources were established form about four shipments of approximately 2 million surviving oysters during the 1940's and 1950's (Thomson 1959); thus a degree of genetic diversity helped to ensure successful establishment and current distribution in Australia includes the states between NSW south and west to South Australia. *C. gigas* was also introduced to WA, but has since become extinct (Thomson 1952). The introduction of *C. gigas* has also presented management implications as an introduced marine species that has established itself on the coastline (Hewitt et al. 2007).

In NSW *C. gigas* complements the production of *S. glomerata* and in some rivers has replaced it entirely in terms of cultivation, while in other rivers *C. gigas* poses an ecological management issue in relation to competition with the native *S. glomerata* (Summerhayes, Kelaher et al. 2009). The benefits to growers of *C. gigas* are faster growth rates and disease resistance to QX. However recent events of mass mortalities of *C. gigas* in NSW, linked to the pacific Oyster Mortality Syndromes (POMS) (NSW DPI 2013), demonstrates that the simple adoption of a new species, and with limited consideration of genetic diversity, is not a panacea to the boom and bust patterns of the oyster industry.

A considerable body of work exists on *C gigas* genetic diversity outside Australia from a wild distribution perspective. However there is no reported wild diversity assessment that has been taken into consideration prior to establishing selective breeding program for this species in Australia. Thus an assessment of the genetic diversity of *C. gigas* in Australian aquaculture in relation to wild genetic diversity is an important first step in determining vulnerability to environmental change, disease and the potential for future stock improvement. As this is a non-native species, background wild diversity is not an optimal comparison to hatchery or cultured stock diversity, as the introduced wild type will have a narrower diversity than the global population. However it provides for a conservative first assessment whereby the opportunity to augment hatchery diversity via the introduction of diploid diversity into new and improved selective breeding approaches.

Molecular assessment of *C. gigas* diversity has been approached using 17 allozyme loci to assess whether naturalization had resulted in erosion of genetic variation (English, Maguire et al. 2000). Three hatchery and four naturalised populations of PO in Australia were compared with one another and with two endemic Japanese populations. All populations showed a high degree of genetic variability. The main finding was that introduced oysters were found to have retained most of the genetic variation present in the Japanese populations. Following on from this work, Appleyard and Ward (2006) characterised the levels and patterns of genetic variation in four successive mass selection lines of Tasmanian hatchery produced stocks of Pacific oysters. These were compared with two feral populations from Tasmania and two endemic populations from Japan. Estimated effective population sizes were about less than 75% that of sex ratio corrected brood stock count estimates (Figure 25). Allele richness was found to be lower in cultured versus native and naturalized populations irrespective of breeding method, with mass selection and family lines compared. This was attributed to an early bottleneck established during the inception of selective breeding. While the mass selection lines clearly lost some variation, this problem is not expected to bear as much weight or consequence as for the *S. glomerata* industry as the existing *C. gigas* selection program in Australia focuses more extensively on family selection and pair matings. However the number of family lines is still relatively low considering the approach used to maximise resilience and productivity in other aquaculture species (Gjedrem et al 2012); thus adaptive capacity to shifting climates and other impacts is reduced.

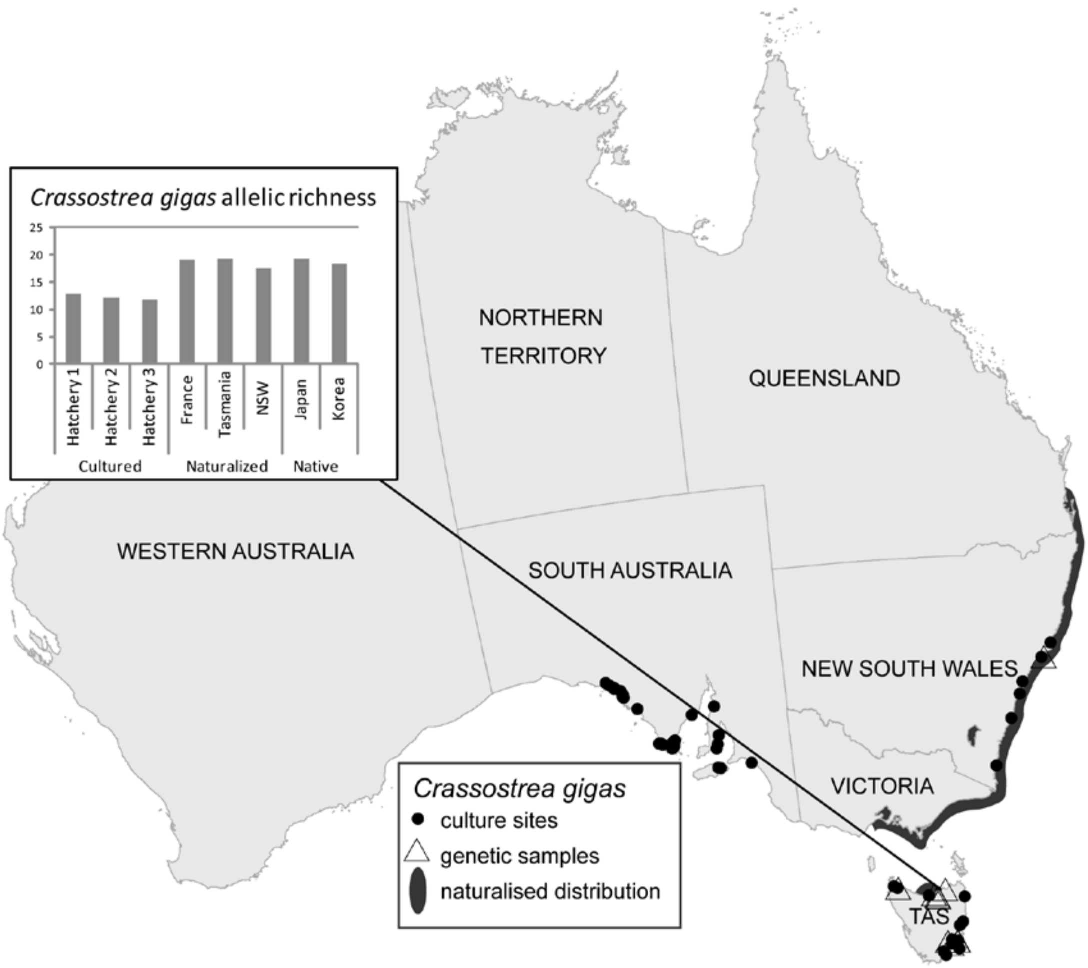



**Figure 25. Current estimated distributions of *Crassostrea gigas* in Australia as sourced from the records of the Australian Museum and OZCAM 2012. Estimates of genetic diversity adapted from English, Maguire et al. (2000) Appleyard and Ward (2006) & Miller (2012).**

## *Ostrea angasi*

*Ostrea angasi*, also known as the native flat oyster (FO), is a large oyster closely related to *O. edulis* (Hurwood, Heasman et al. 2005) which has been the oyster of choice in Europe in the past centuries. The distribution of this species in Australia is extensive and embraces the southern region of the continent where few other oyster species (e.g. *Saccostrea* spp.) are found (Figure 26). The cultivation efforts of this species have been sporadic and extend back into the mid 1900's, following the decline of wild harvest production (as reviewed by Nell 2001). This lack of sustained effort to establish *O. angasi* as a substantial aquaculture industry was in part circumstantial, in part due to knowledge about the decline of the European flat oyster industry, but also due to the success of hatchery establishment and cultivation of *C. gigas*. Despite this, there is renewed interest in establishing the cultivation of this species in both Victoria and South Australia (industry comments) following an ongoing albeit small hatchery and cultivation industry in NSW since 1998 (Nell 2001).

As *O. angasi* has not been the focus of commercial oyster production, genetic work is limited to that of wild diversity. However in contrast to *S. glomerata* and *C. gigas*, that effort has been considerably larger. *Ostrea angasi* was surveyed for wild diversity in NSW while under consideration for potential culture (Hurwood, Heasman et al. 2005). Low genetic diversity within the NSW estuaries surveyed suggested that there should be no restriction for translocation of populations within this region (Figure 26). Some increase in genetic structure is evident between the east and west coasts of Australia, however this is much less than expected given reproductive biology of the species as a brooder of larvae rather than a broadcast spawner as for the other oyster taxa (Foighil & Taylor 1999). More sensitive, population-genetic tools are now available to detect more cryptic patterns of genetic diversity within this species and will be important should this species be considered for selective breeding.

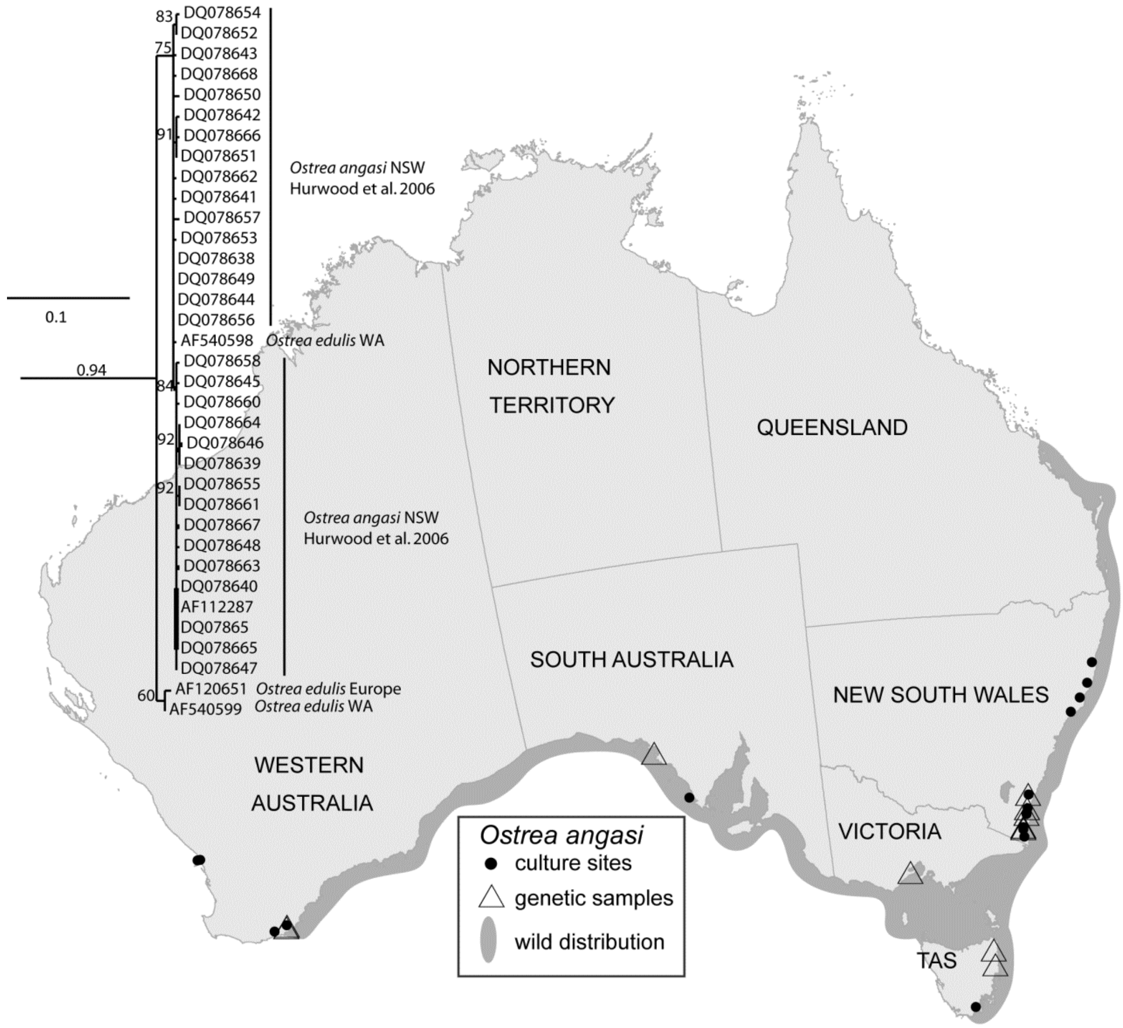



**Figure 26. Current estimated distributions of *Ostrea angasi* in Australia as sourced from the records of the Australian Museum and OZCAM 2012. Estimates of genetic diversity adapted from Hurwood, Heasman et al. (2005).**

This review demonstrates that the diversity of oyster species and genetic resources in Australia is poorly understood, yet the current synthesis of phylogeographic information suggests a nation with geographically wide ranging and untapped richness in genetic resources across 7 oyster species with commercial potential. A limited number of studies demonstrate that the cultured diversity maybe as low as 25% of that of wild diversity for the iconic *Saccostrea glomerata*, while *Crassostrea gigas* cultured diversity is at 75% of some wild populations. This review establishes that the characterization and monitoring of genetic diversity, a precursor to selective breeding programs, is a critical weakness in the Australian oysters industry. However it also demonstrates that there is a clear opportunity to target increased genetic resources to sustain and facilitate adaptation of the oyster industry in a changing climate.

# Communication and Extension Action Plan

Throughout the project activities towards the dissemination and extension work of the Oyster Information Portal development and outcomes were undertaken as follows:

| |
|---|
| Brochure/ Page summary – project summary to disseminate project idea and methods among the oyster industry and other beneficiaries. Summary was sent by email and distributed by hand at organised oyster meetings targeting 80% of the oyster industry in the NSW Southern Rivers region and a 50% of the industry in the Northern Rivers region<br>Additional brochure was created in collaboration with NCCARF and Oceanwatch Australia as part of the National Climate Change Adaptation research Plan (NARP) for Marine Biodiversity & Resources<br>http://www.nccarf.edu.au/content/objectives-and-methods-6<br>http://www.aquaculture.org.au/images/downloads/Presentations/38-Rubio.pdf |
| Media releases informing the general public along the coast of NSW about the project aims and expected outcomes. http://media.uow.edu.au/releases/UOW098868.html<br>Television/ Radio interviews explaining the project and its importance -media in ABC Wollongong |
| Reporting to steering committee every 2-3 months using web-interface software. A total of 7 meetings have been organised |
| Reporting to stakeholder committee every 6 months via email (i.e update report summary) |
| Industry workshops consultation with growers from 4 study sites:<br>1) Reporting / feedback via email / phone conversations – twice a year per location<br>2) Workshops (face-to-face, with laptops) at the study areas – 3 times per location |
| National industry workshop targeting oyster industry members from other Australia states – workshop in conjunction to the International Oyster Symposium in Hobart- Sept 2011 |
| Present results at National/ International aquaculture conferences and industry field days<br>(2 per year)<br>International Oyster Symposium (a poster and an oral presentation) http://www.oysterstasmania.org/resources/ios4-presentations-a-proceedings<br>http://www.uow.edu.au/content/groups/public/@web/@sci/@smfc/documents/doc/uow113577.pdf<br>Australasian Aquaculture, Melbourne 2011 (2 oral presentation)<br>http://www.aquaculture.org.au/images/downloads/Presentations/38-Rubio.pdf<br>2012 NSW Coastal Conference (2 oral presentations)<br>http://www.coastalconference.com/2012/papers2012/Ana%20Rubio%20Full%20Paper.pdf<br>http://www.coastalconference.com/2012/papers2012/Chelsea%20Nash%20Full%20Paper.pdf |
| Electronic Newsletter update every 3 months to those industry members and stakeholders that subscribe to it. This newsletter was an initiative developed in collaboration with Oceanwatch Australia with the aim of promoting and disseminating both of our current oyster projects. http://www.oceanwatch.org.au/our-work/ems-nsw-oysters/<br>Additional articles in other newsletters edited by NSW DPI Fisheries http://www.dpi.nsw.gov.au/fisheries/aquaculture/publications/newsletter<br>Newsletter by NSW Farmers Association http://www.nswfarmers.org.au/advocacy/livestock/oysters |
| Project website- web-based proof-of-concept spatial information portal for natural resources and the oyster industry. The portal will hold information on the project and instructions on how to use the portal. In addition the website also has relevant information to oyster industry members and stakeholders on climate projections, information on the governance of the industry, link to important sections of oyster stakeholders' websites; latest results of the oyster monitoring program and link to relevant reports and publications<br>http://www.oysterinformationportal.net.au/ |
| Peered- review journal publications of project results or outcomes for dissemination among the scientific |

community (*In draft*)

Other resources:

Industry Magazines- An article on the Oyster Monitoring Program was featured in the Austasia Aquaculture vol 26 (2) Winter 2012 http://www.oysterinformationportal.net.au/wp-content/uploads/2012/03/AustAsiaAquaculture.pdf

Presentations at other events:

10/10/2010- Shellfish Workshop in SA organized by PIRSA and Food Authority

21/2/2011 – OIP concept presented to NSW DPI Fisheries at Port Stephens

28/2/2011- OIP concept presented to TERN, CSIRO Marine & Atmospherics and Atlas of Living Australia

23/3/2011- Presentation to Shoalhaven Oyster growers about Honours students results on water quality in the Shoalhaven and it's link to the OIP

20/4/2012 – Integration of OIP into the CSIRO Coastal Research data portal http://coastalresearch.csiro.au/?q=node/758 09/5/2012 – Presentation of the Proof of concept of OIP to the Coastal Management Working group organized by the SRCMA

18/5/2012- Presentation of the Proof of concept of OIP to NSW DPI Fisheries in Port Stephens

30/5/2012 – Presentation on the progress of the OIP to the SRCMA Board

07/6/2012- OIP Webinar to portal and spatial information stakeholders through the Office of Spatial Data Geonetwork

01/11/2012- Presentation to Shoalhaven City Council Natural Resource Management Committee

13/11/2012 – Presentation at the Shoalhaven Heads Focus Group

16/11/2012 – Launch of the OIP- Presentation and webinar

# OIP launch

In conclusion to the suite of stakeholder relevant outputs from this project, a formal launch for the completion of the Oyster Information Portal tool was organised on Friday 16th November, 2012 at the University of Wollongong Shoalhaven Campus (Figure 27). At the launch the overall objectives and background of the project were presented including a demonstration of the Oyster Information Portal. This was followed by a series of brief seminars on other projects related to the portal project or the oyster industry that researchers at the Shoalhaven campus have been involved in during the last 2 years. Approximately 30 people attended the event in person in addition to representatives of the industry and included NSW DPI Fisheries, Environmental Management Systems Officers for the oyster industry, Local Government staff and FRDC representatives.

SHOALHAVEN MARINE & FRESHWATER CENTRE | UNIVERSITY OF WOLLONGONG

**The Shoalhaven Marine and Freshwater Centre invites you to "The Oyster Platter Seminar"**

**- a public seminar and webinar on Friday 16th November for the launch of the 'Oyster Information Portal'**

To be held in the GSM Lecture Theatre at the Shoalhaven Campus
3pm refreshments in foyer, 4pm seminars followed by
Shoalbites Cafe Oyster Platter & drinks at 5pm.

PLEASE RSVP: **tmyers@uow.edu.au** 02 4448 0816
indicate: "Oyster Webinar Invitation please" &/or "I will attend the Oyster Platter seminar drinks"

**The Oyster Information Portal: An online estuary Google towards healthy rivers and oysters:** ***Pia Winberg & Ana Rubio***

Pia Winberg is the Director of the Shoalhaven Marine and Freshwater Centre at the University of Wollongong. Pia's main research interest is in sustainable marine food production systems, integrated with the coastal and marine environment.

Ana Rubio's research revolves around marine ecology and aquaculture. During the last 10 years she has been working closely with the NSW edible oyster industry.

**The Unique Sydney Rock Oyster Genes and how can we protect this resource:** ***Lisa Kirkendale***

Lisa Kirkendale uses molecular data to address research questions in marine systems. Lisa has been assessing the status of genetic knowledge concerning commercial oyster resources in Australia.

**Stressing out our oysters:** ***Andrew Wakefield***

Investigating the response of the Sydney Rock Oyster to environmental stressors associated with a changing climate.

**Omega-3 rich oysters - when and where to get your healthiest dose:** ***Claire Taylor***

Omega-3 and oysters: how does the environment and genotype alter PUFA profiles in the Sydney rock oyster and the triploid pacific oyster?

**The OMP - a science, industry and government initiative to track oyster condition:** ***Chelsea Nash/Ana Rubio***

In 2011, an oyster monitoring program commenced in the South Coast of NSW. The estuary-wide monitoring program utilises automated graders to assess oyster performance (growth & mortality) every two months by collecting information that can be used to identify changes over time.

Australian Government Fisheries Research and Development Corporation | Australian Government Department of Climate Change and Energy Efficiency | BVSC | NSW Catchment Management Authority Northern Rivers | NSW Catchment Management Authority Southern Rivers

**Figure 27. OIP Launch promotional brochure**

# Discussion

This project has demonstrated the current limitations to data availability and integration across jurisdictions that are the stakeholders of estuarine management, and custodians of data. Thus the OIP demonstrates the need for the collation and integration of existing environmental and industry data into a central repository that is publically available to researchers, catchment managers, industries and community. In this project we focused on priorities common to both the oyster industry and catchment managers that would facilitate better management of the industry and catchments.

Through intensive consultation it was found that information on water quality and catchment impact related actives was a top priority for all stakeholders (i.e. industry members and catchment managers inclusive). In particular, changes in water quality, which has been identified in previous industry reviews (Leith and Haward, 2010), was the number one priority and information need for the oyster industry as their livelihood strongly relies on optimal water quality conditions. Water quality issues are of particular concern currently due to intensive catchment development and coastal population growth increase, which are both imposing additional stress to estuarine ecosystems and to the industries that rely on these systems.

Through the diverse agencies, there are extensive data sets that are relevant to the industry and natural resource managers. The challenge in consolidating all of this information into the OIP was the lack of standardized data management and processing, including limited amounts of metadata to even describe the data context. Scenarios and a workflow was identified to highlight the top down initiatives and information infrastructure that can facilitate the sophistication of estuarine monitoring programs that come from the ground up; however these require coordination.

Over 20 custodian data sets were included and developed within the OIP in each of four key estuary areas in NSW. This included tens of thousands of monitoring points across thousands of sites. In summary, the proof-of-concept of the OIP demonstrated a tool that could deliver effective dissemination of coastal and environmental information that has been difficult to access for industry stakeholders and natural resource managers. Some examples of the usefulness of the data and information contained within OIP delivered clear and diverse indicators for change, including a decadal shifts in the estuarine primary producers, phytoplankton. Oyster condition and productivity data suggested that spatial management options could be developed as an adaptive strategy to enhance the productivity within rivers based on environmental shifts, and maybe one day climate change adaptation options. Finally a thorough review of the genetic resources of the oyster industry highlighted an untapped potential of the available genetic resources that could provide for some adaptability to climate change scenarios in Australia. Thus data from the OIP delivers a capacity for clear evidence of change, solutions to practical management as a form of adaptation at the level of the farmer, as well as longer term investment opportunities in targeting improved genetic management to deliver more robust, diverse and adaptable strains of oysters.

# Conclusion

The benefits of collating environmental and industry data have been demonstrated here through the prototype OIP. The information contained in the portal has assisted the oyster industry and catchment managers to get a spatially resolved perception of the information available for each catchment. This helps to identify knowledge gaps and risks. It has also assisted the industry in becoming better informed about natural processes placing them in better position to plan for future environmental, including long term climate change. Information contained the in OIP has also assisted in the delivery of information for stakeholders and governance organizations to identify high risks, improved monitoring and target catchment remediation work.

The OIP is one of many data repositories that are emerging. However the OIP was developed using a bottom-up approach in which the end-users of the portal and their needs were identified from the outset. Thus the OIP is uniquely useful from the start in contrast to top down initiatives that have long term vision for user uptake. As a result we recommend that this tool will be pursued with a mandate to resource and streamline the coordination of data that is publicly funded and can easily become discoverable, accessible and meaningful for the oyster industry and natural resource managers alike.

# Implications

It is evident that the greatest challenge in value-adding to and achieving significant returns on current investment in estuarine monitoring systems and data, is simply logistical. The technology is available, and the information infrastructure has been invested in. Thus the further investment of resourcing and mandating a government node to establish, coordinate, quality control the management of data, metadata and the repository thereof is a priority. In addition it is a prerequisite for the push towards any knowledge action and informed adaptation options for in light of climate change; without which, investment in monitoring programs does not serve society well.

The future of the OIP concept requires both the identification of the business case to resource the ongoing maintenance and updating or upgrading of the OIP, as well as the identification of current and developing information technologies that can facilitate a more sophisticated and less labour intensive process. Industry members suggested that a recently formed industry body, Oysters Australia, might be the best entity to support and host this type of portal as they represent the current national oyster body. However interest and resources are currently not available in this emerging industry body that represents one stakeholder group. A more viable solution would be to develop the OIP towards servicing the natural resource management sectors that have the same information priorities as the oyster industry. This includes numerous local government, food safety authorities, fisheries authorities and other natural resource management agencies. It is anticipated that this collective interest model would more easily secure resources that can provide adequately for ongoing maintenance, thus the model becomes a greater stakeholder and industry resource with multiple objectives and mandates on very similar content. The potential exists to expand on this concept to include undertaking monitoring data management and processing on behalf of custodians and according to Australian standards and National IT infrastructure.

# Recommendations

## Further development

The future technology of OIP will need to harness the emerging software and data intelligence systems. Eventually such systems will provide for direct harvesting of not only metadata, but the data resource itself from repositories. Thus this project identified the emerging direction of this technology and transferred one estuary instance to a Business Intelligence Platform.

### *Technical Architecture Overview*

A future technology for the OIP concept employs Yellowfin BI (Business Intelligence) proprietary software for the data layers and GeoServer open-source software to feed ancillary layers into Yellowfin. Data sources from OIP and its external data providers are uploaded to the Data Staging Area (DSA). Using Pentaho Data Integration software, these datasets are then extracted from the DSA, integrated, consolidated into a data warehouse environment optimised for the BI layer. As well as housing the raw external datasets, the DSA also captures associated metadata descriptions.

In the following subsections we outline the software used, the way that the software components fit together and interact, and the workflows involved in using the dashboard and metadata systems.

### *Selected software technologies*

PostgreSQL on Linux (Ubuntu) virtual machines is used to provide a fast, stable and standards compliant database, with excellent geospatial extensions (PostGIS), a key requirement for analysis and display of infrastructure data.

Yellowfin and GeoServer are installed under and run from Apache Tomcat.

GeoNetwork and GeoServer are open source, open data mapping projects that provide mapping services for the metadata and dashboard respectively. GeoNetwork focuses on managing, searching for (by metadata) and displaying spatially-referenced resources. GeoServer focuses on display and editing of geospatial data.

Pentaho Data Integration (Kettle) is selected as a mature and open-source-licensed ETL package.

Microsoft internet security and acceleration (ISA) reverse proxy is supplied by IT services to provide acceleration of web requests as well as extra security (as detailed below).

### *Software components and interactions*

Software components are shown in Figure 28. The back-end is called the Data Staging Area (DSA) and consists of flat files, Kettle, and a staging RDBMS area (running PostgreSQL) to hold data tables prior to a transfer overnight into the main database.

Right at the start of the front-end we use a reverse proxy. A reverse proxy is used for two reasons:

- Speeding access to the web front-end, particularly by caching images (mainly icons) used across pages.
- It lets us move the web front-end behind a firewall, and additionally allows good visibility and filtering of web requests to the web front end.

The dashboard web-server provides access to the BI layer (Yellowfin) where data analysis and visualisation are performed. Geospatial services are provided by GeoServer. Both services run on the

Apache Tomcat platform, which provides a web server for hosting services that run using the Java Virtual Machine (JVM) software execution environment.

The metadata system, for discovering data sets that exist in the infrastructure databases, similarly uses Apache Tomcat to host GeoNetwork and a set of search & retrieval workflows defined using the open source Bonita workflow and business process modelling software.

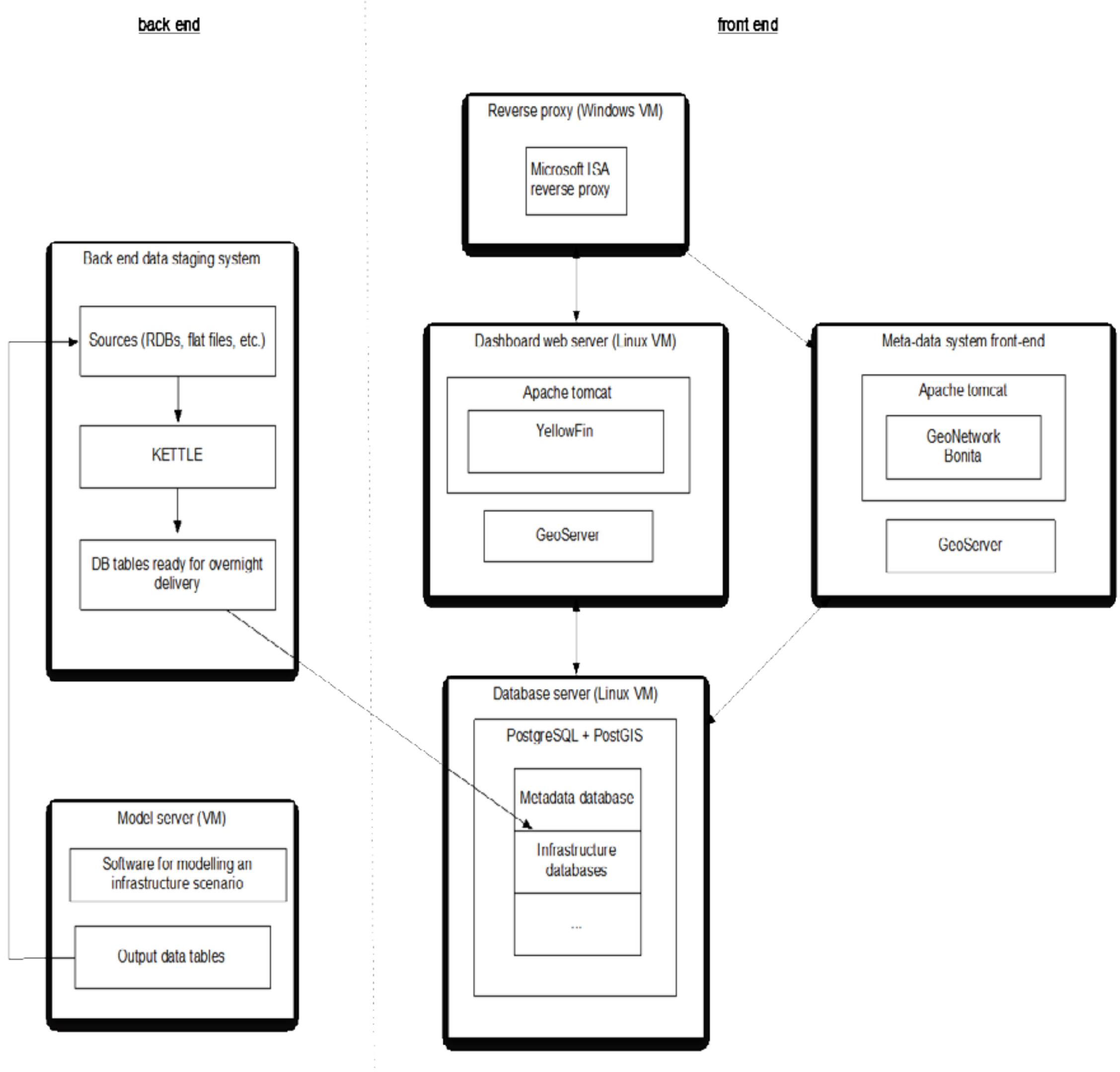



**Figure 28: IT Architecture of the SMART Infrastructure Dashboard.**

### *Hosting infrastructure*

#### *Virtualised services*

All of the machines are running as virtual machines on a physical machine running the VMWare ESX virtualisation platform. Virtualising these allows to version control the platform, create snapshots for easy restore.

### *Security*

The web front end is on a private LAN behind the University's firewall, and the database server is further restricted by being on a private LAN separate to and firewalled from the main private LAN used at the University.

### *NAS share for SQL database files*

The set of files physically underlying the database are located on a NAS (network attached storage) server that provides good disk and network performance.

### *Process monitoring*

We are using the Nagios 3 platform for monitoring the virtual machines we use.

This is a web-based platform for monitoring a set of servers from a single web page, and supports email notifications if any issues are detected.

### *Backup & restore*

Snapshots of the virtual machines are created every hour. These snapshots are also copied to a separate site, and can be brought up on a physical machine running VMWare at that site within a two hour time frame if the main site is down. This separate site is geographically separate and has its own connections to the Internet.

## ***Supporting services***

### *Geotools / geospatial*

One key aspect of Yellowfin BI that makes it stand out from the rest of BI software is its excellent capability to handle geospatial datasets including vector (point, lines and polygons) and raster data. We benefit from this capability by using mainly Yellowfin's mapping to generate highly interactive map-based reports that are used as stand-alone reports or as embedded reports in dashboards.

Yellowfin also supports Web Mapping Services (WMS) to enrich those map-based reports. We use GeoServer to serve various ancillary spatial data as WMS layers that are then accessed by Yellowfin map-based reports.

Currently, we use ArcGIS software to edit spatial data prior to loading into PostgreSQL/PostGIS. However, we will be integrating GeoKettle to handle most of these operations in the next iteration. Basically, GeoKettle is a spatially-enabled version of Kettle that incorporates open source geospatial toolkits such as JTS, GeoTools, degree, OGR and, via a plugin, Sextante.

### *OIP Reports*

*How to access OIP Dashboard*

The following details required to access OIP Dashboard:

| | |
|---|---|
| **URL:** | **http://sid-dev.its.uow.edu.au:8080/** |
| **Username:** | **oip@uow.edu.au** |
| **Password:** | **oip@sid** |

### *Summary of OIP reports*

| No. | Report Name | Figure # |
|---|---|---|
| 1 | Area Map | 2 |
| 2 | MHL – Water Level | 3 |
| 3 | NSW Office of Water – Water Level & Discharge | 4 |
| 4 | OZ Coast Water Quality | 5 |
| 5 | Points Map with Drill Through | 6 |
| 6 | SCC Water Quality - Bacteriological & Nutrient | 7 |
| 7 | SCC Water Quality - Chlorophyll a | 8 |
| 8 | SCC Water Quality - Dissolved Oxygen | 9 |
| 9 | SCC Water Quality – pH | 10 |
| 10 | SCC Water Quality – Physical | 11 |
| 11 | SCC Water Quality – Salinity | 12 |
| 12 | SCC Water Quality - Total Phosphorus | 13 |
| 13 | SCC Water Quality – Turbidity | 14 |
| 14 | Sydney Rock Oyster Production | 15 |

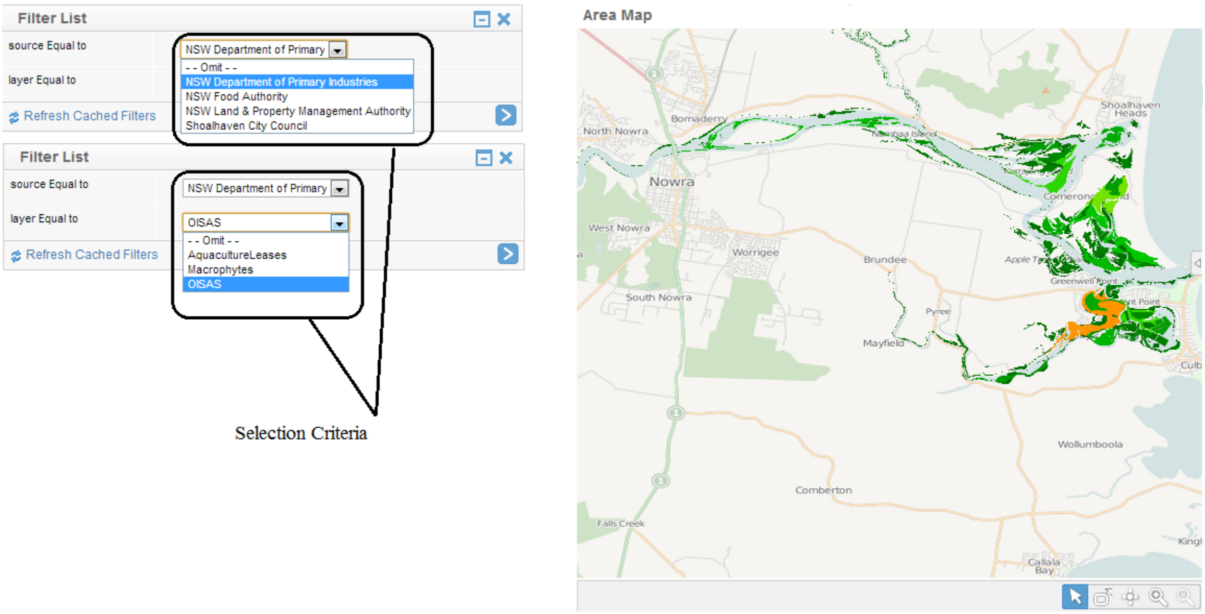



**Figure 29. Area Map of the OIP in the Yellowfin BI data stage area (DSA) output.**

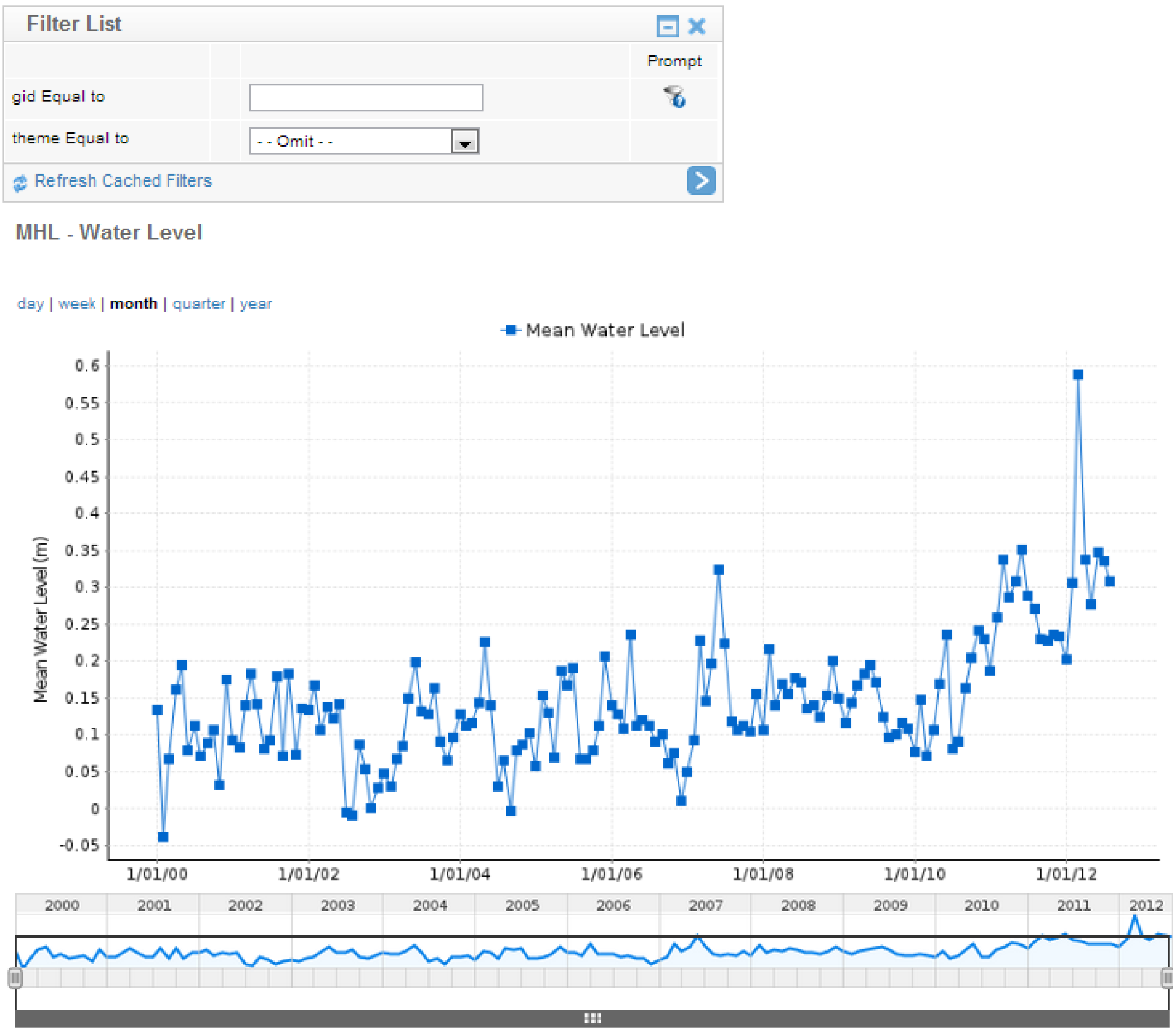



**Figure 30. Manly Hydraulics Lab – Water Level data outputs in the Yellowfin BI DSA output.**

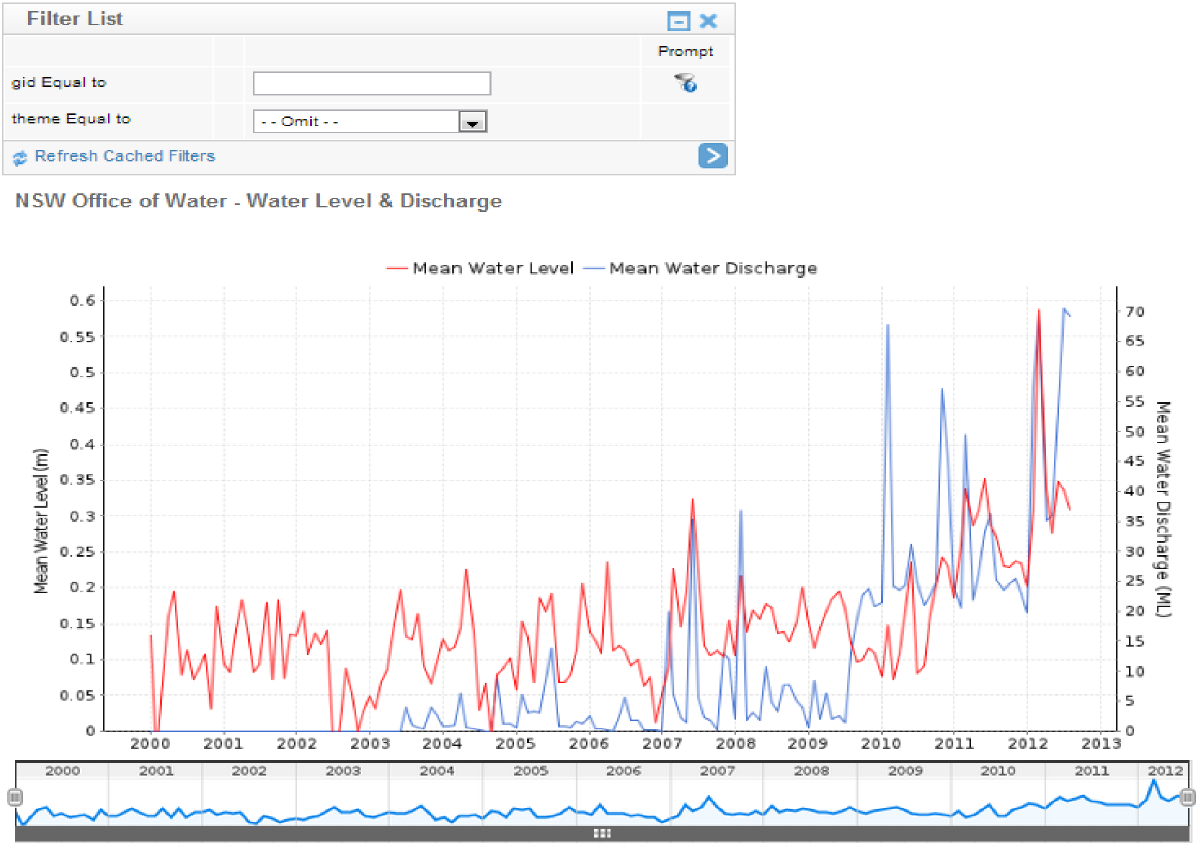



Figure 31. NSW Office of Water – Water Level & Discharge Yellowfin BI DSA output.

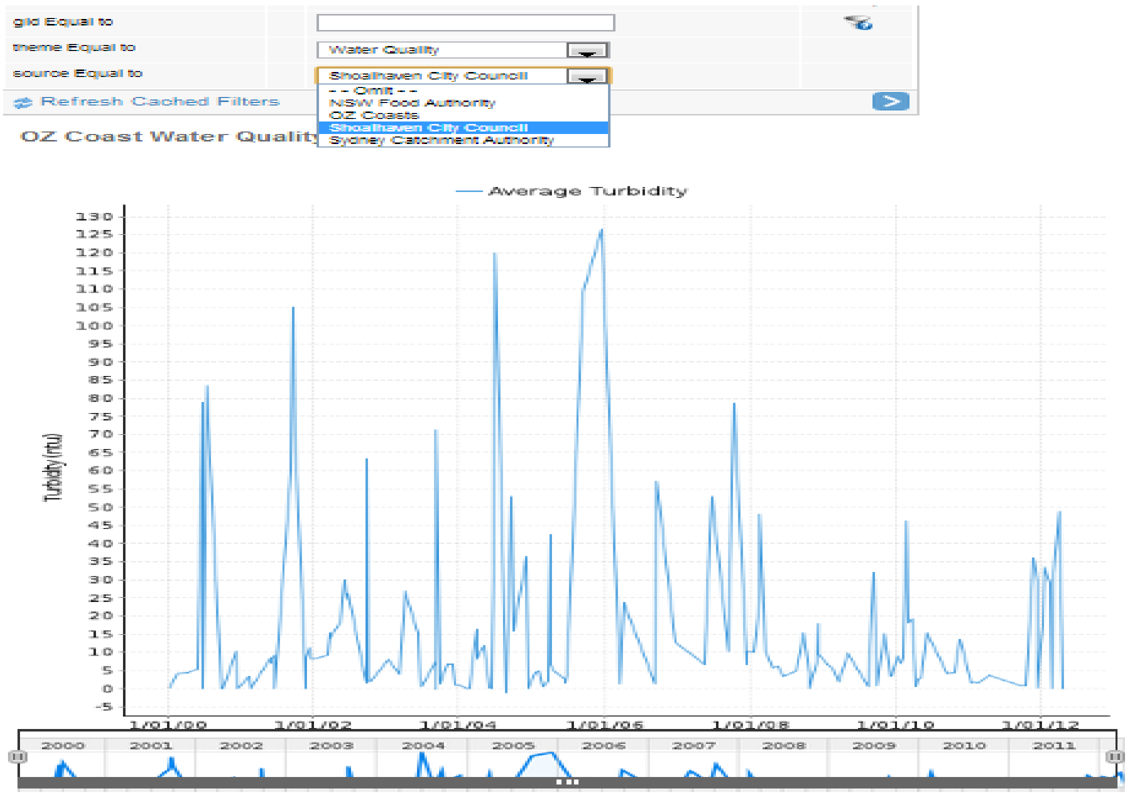



Figure 32. OZ Coast Water Quality data in the Yellowfin BI DSA output.

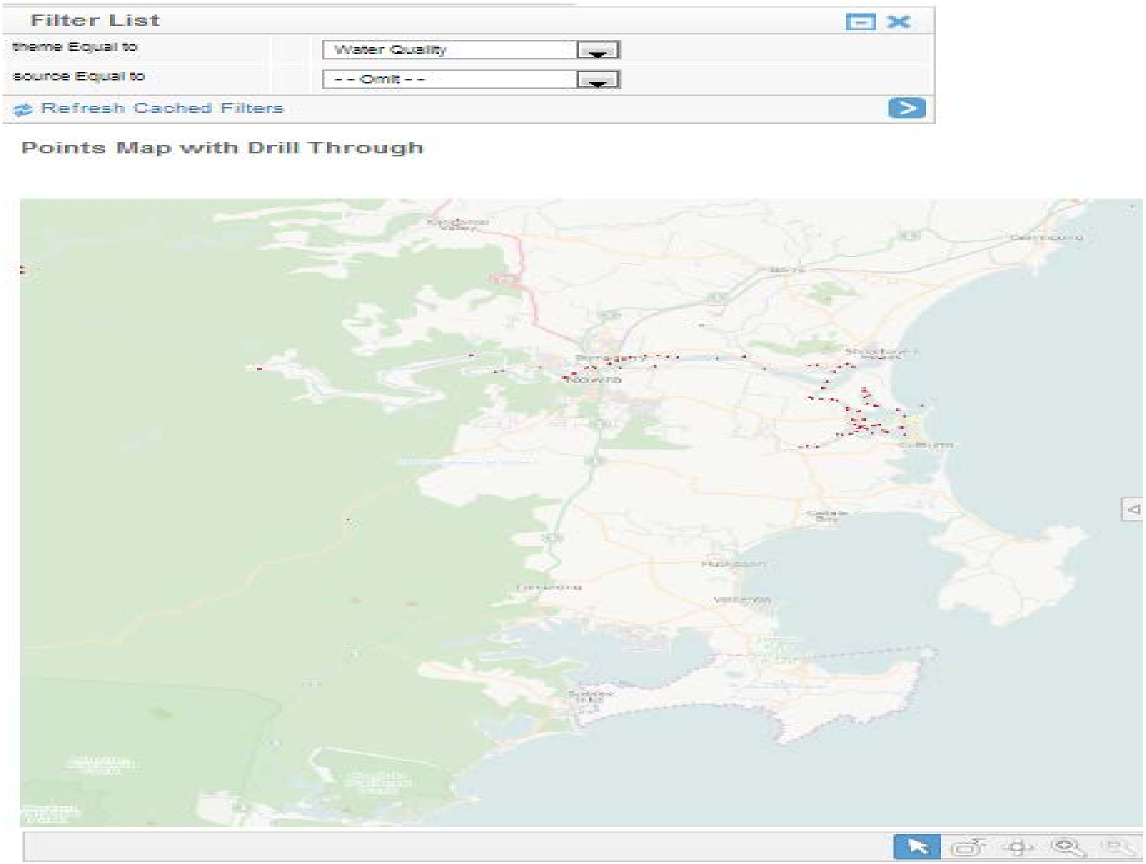



**Figure 33. Points Map with Drill Through from Water Quality sampling sites**

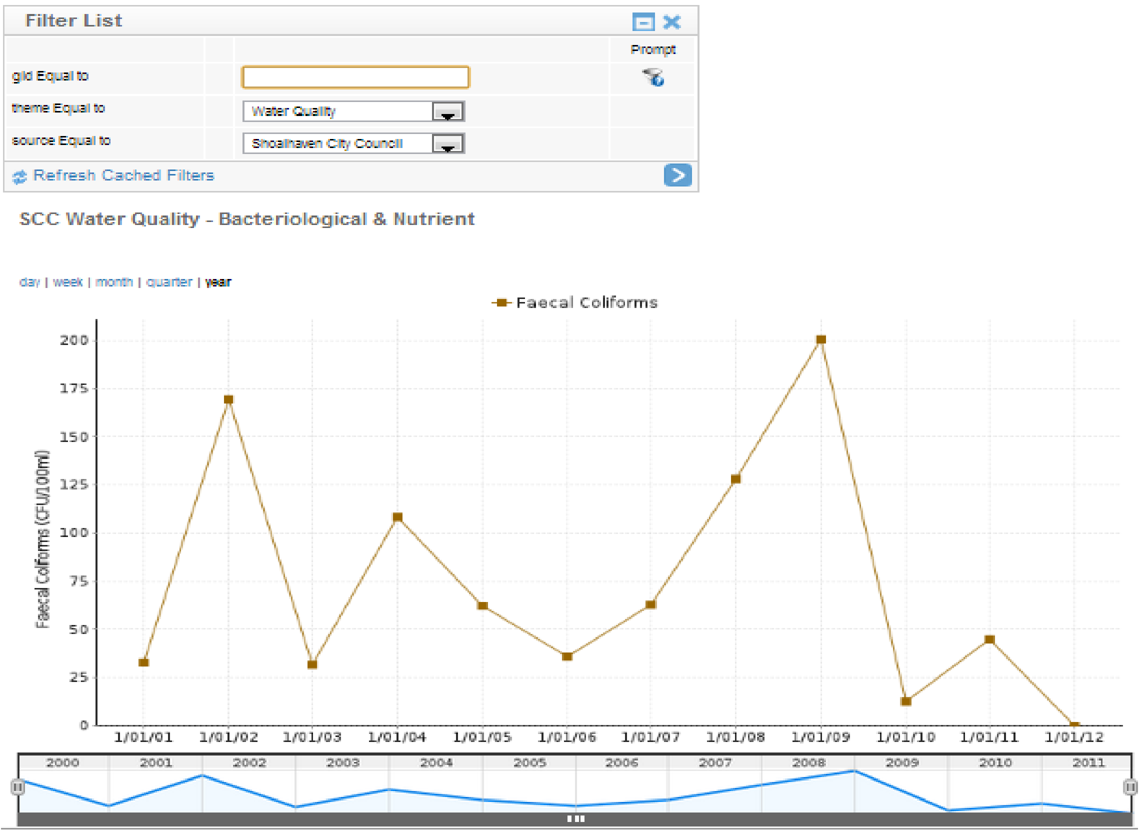



**Figure 34. Shoalhaven City Council Water Quality - Bacteriological & Nutrient data in the Yellowfin BI DSA output.**

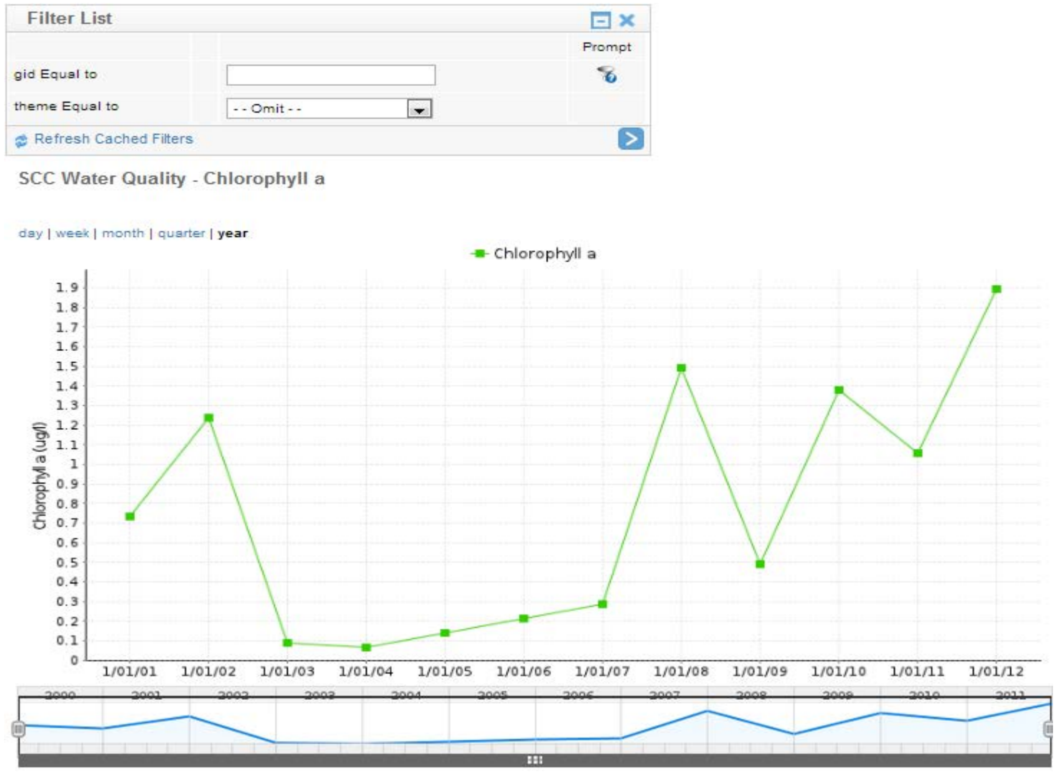



**Figure 35. Shoalhaven City Council Water Quality – Chlorophyll-a data Yellowfin BI DSA output.**

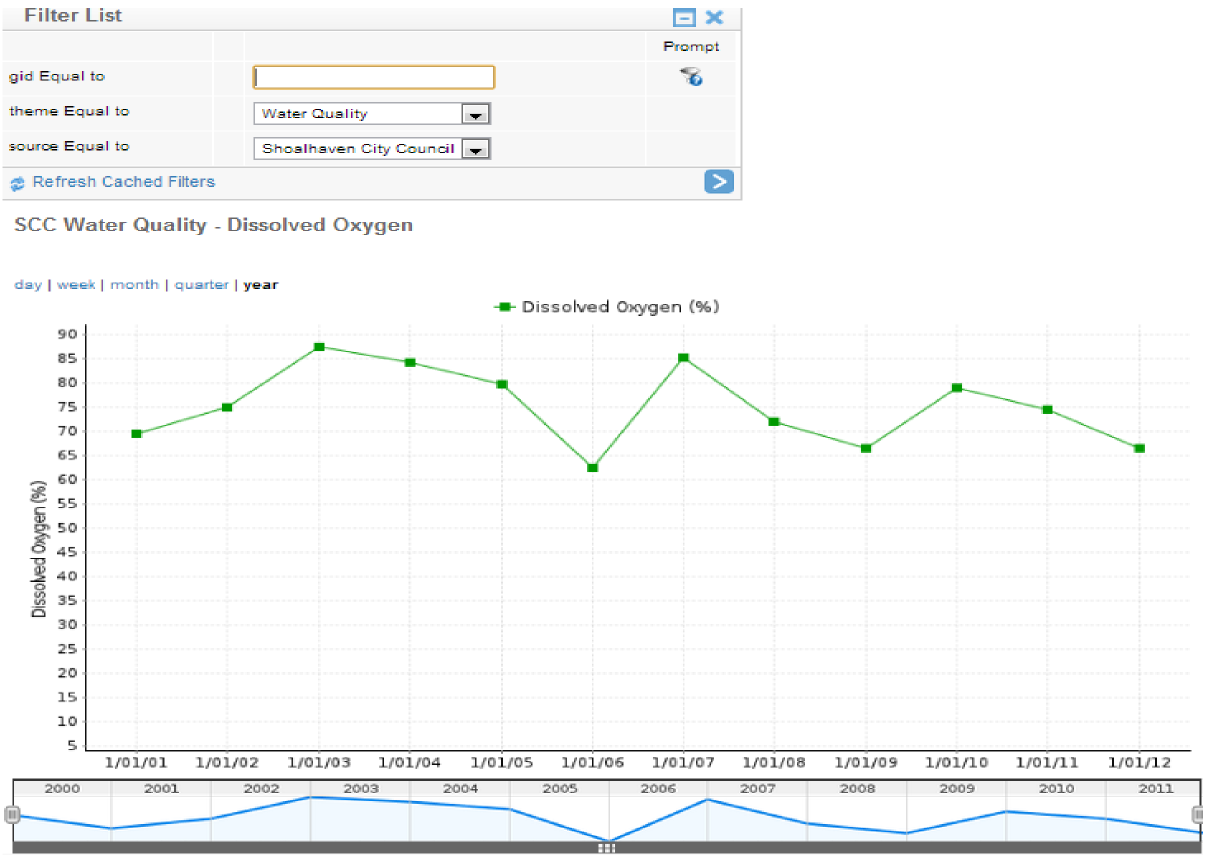



**Figure 36. Shoalhaven City Council Water Quality - Dissolved Oxygen**

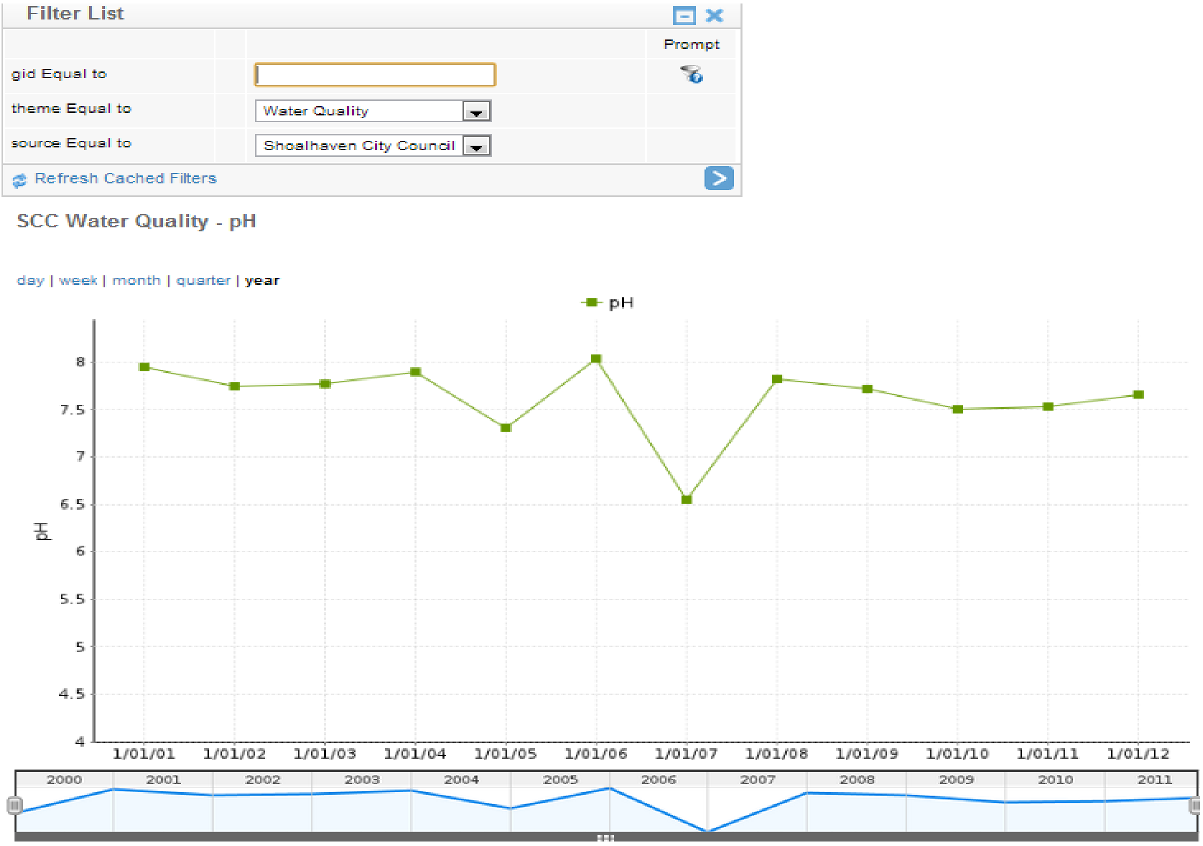



**Figure 37. Shoalhaven City Council Water Quality – pH**

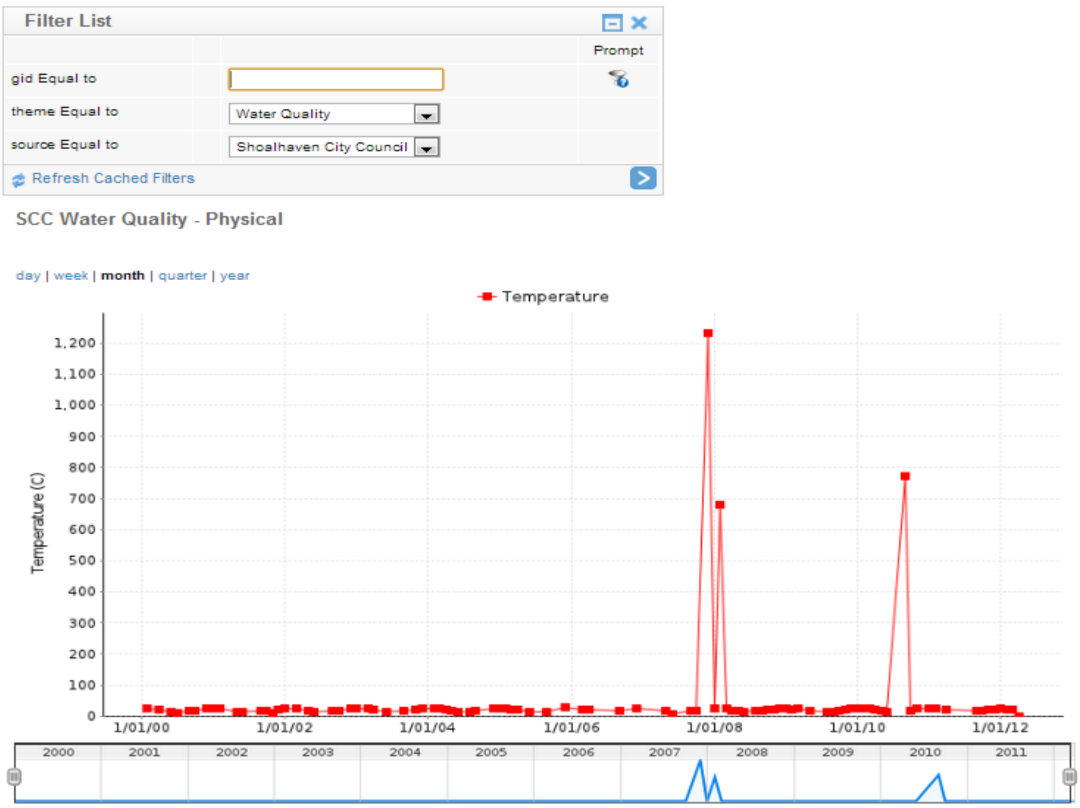



**Figure 38. Shoalhaven City Council Water Quality – Physical**


**Figure 39. Shoalhaven City Council Water Quality – Salinity**

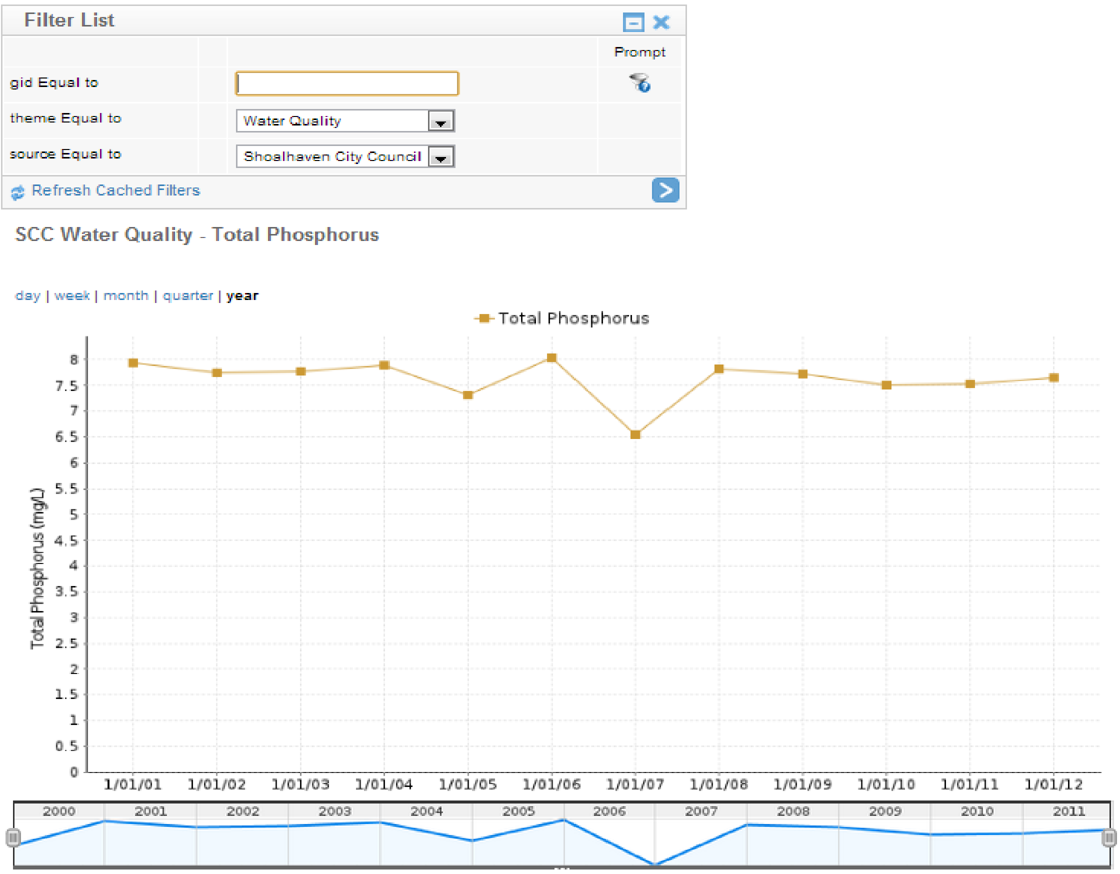



**Figure 40. Shoalhaven City Council Water Quality - Total Phosphorus**

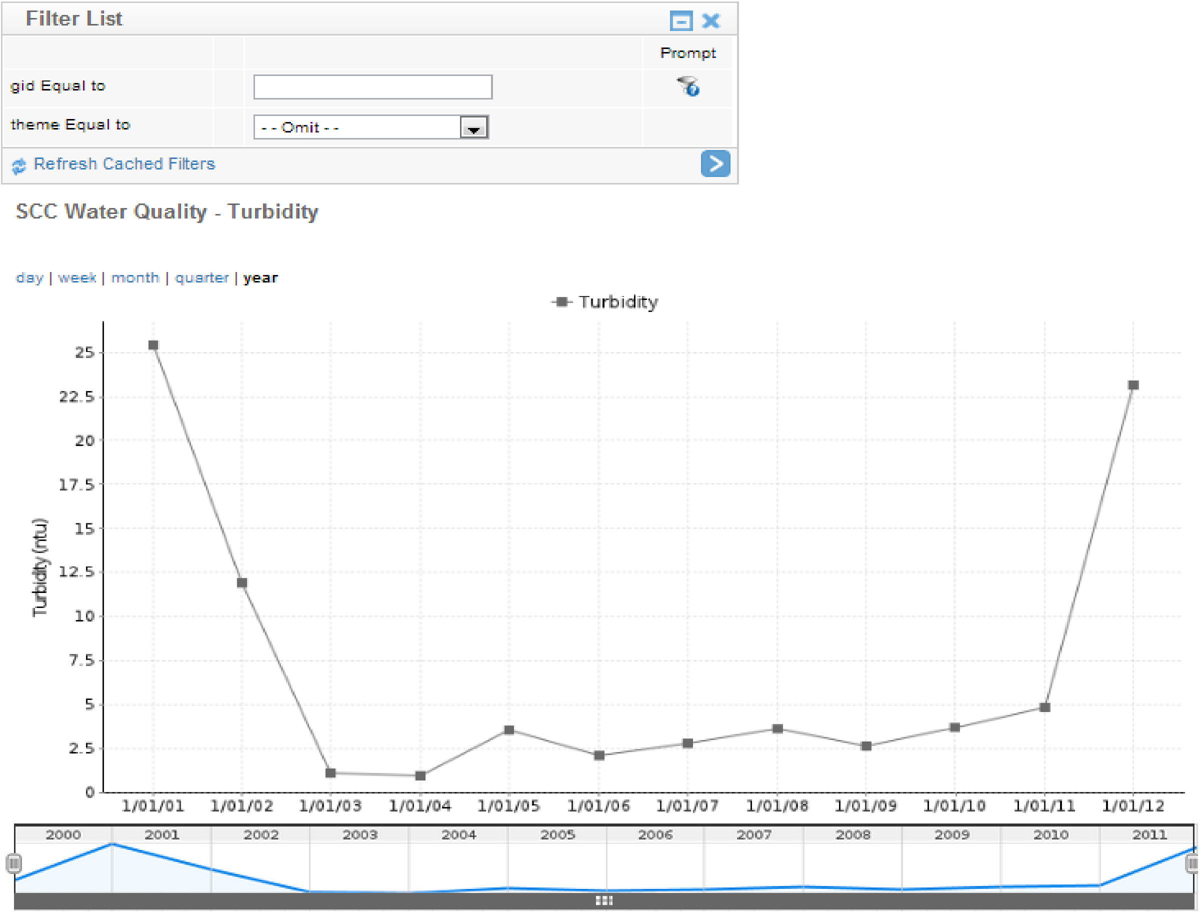



**Figure 41. Shoalhaven City Council Water Quality – Turbidity**

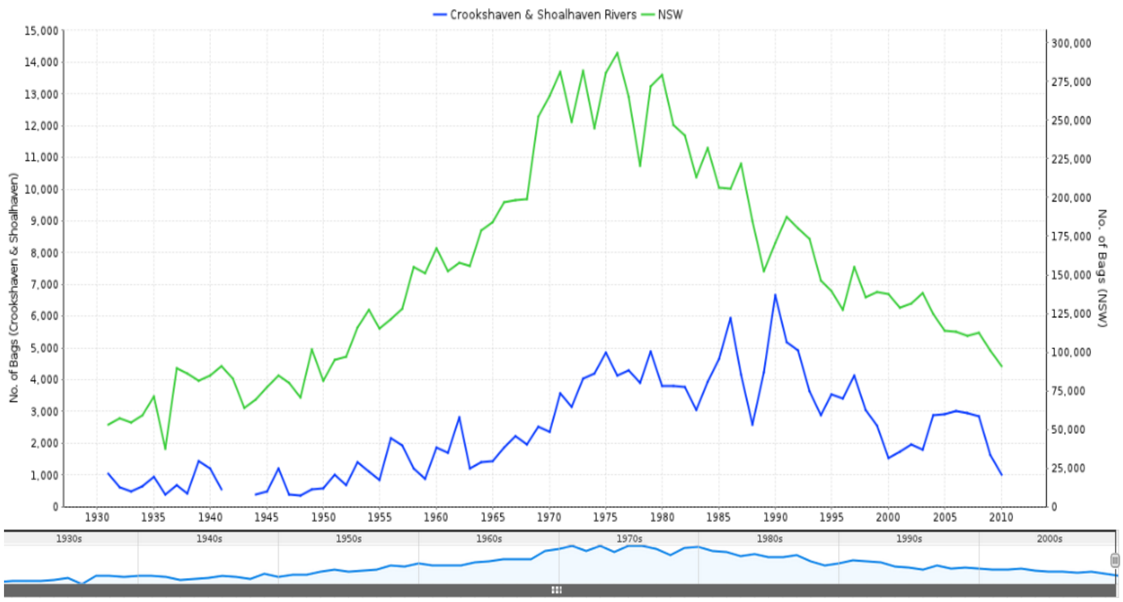



**Figure 42. Sydney Rock Oyster Production in the Shoalhaven and Crookhaven Rivers**

### *Dashboard*

The Dashboards pull information from a variety of sources and display them all in one place. It can help to integrate different parts of the organisation. It is a powerful way to provide real time information to allow managers to make the appropriate decisions based on their dashboard analysis (see Figure 29 – OIP Dashboard).

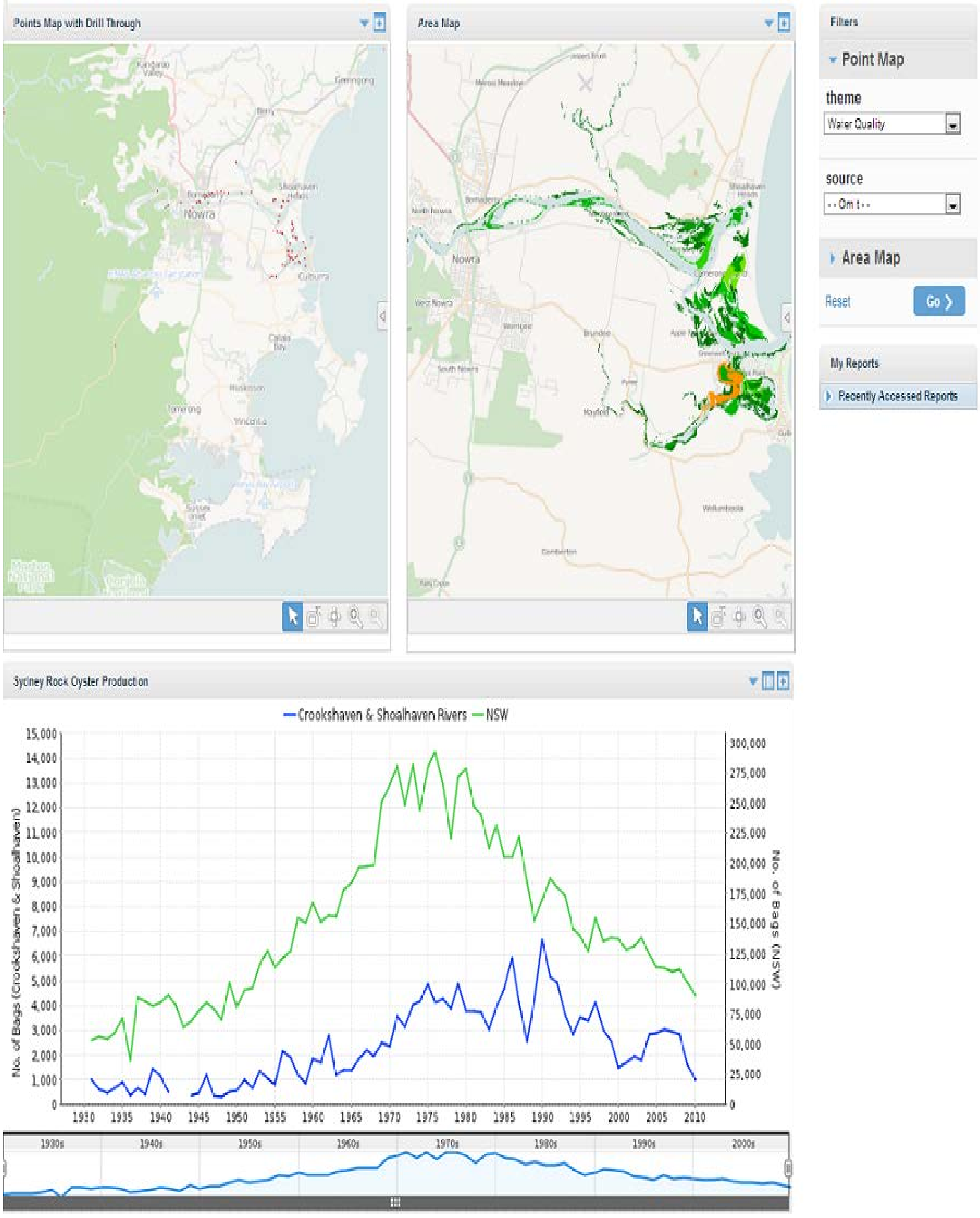
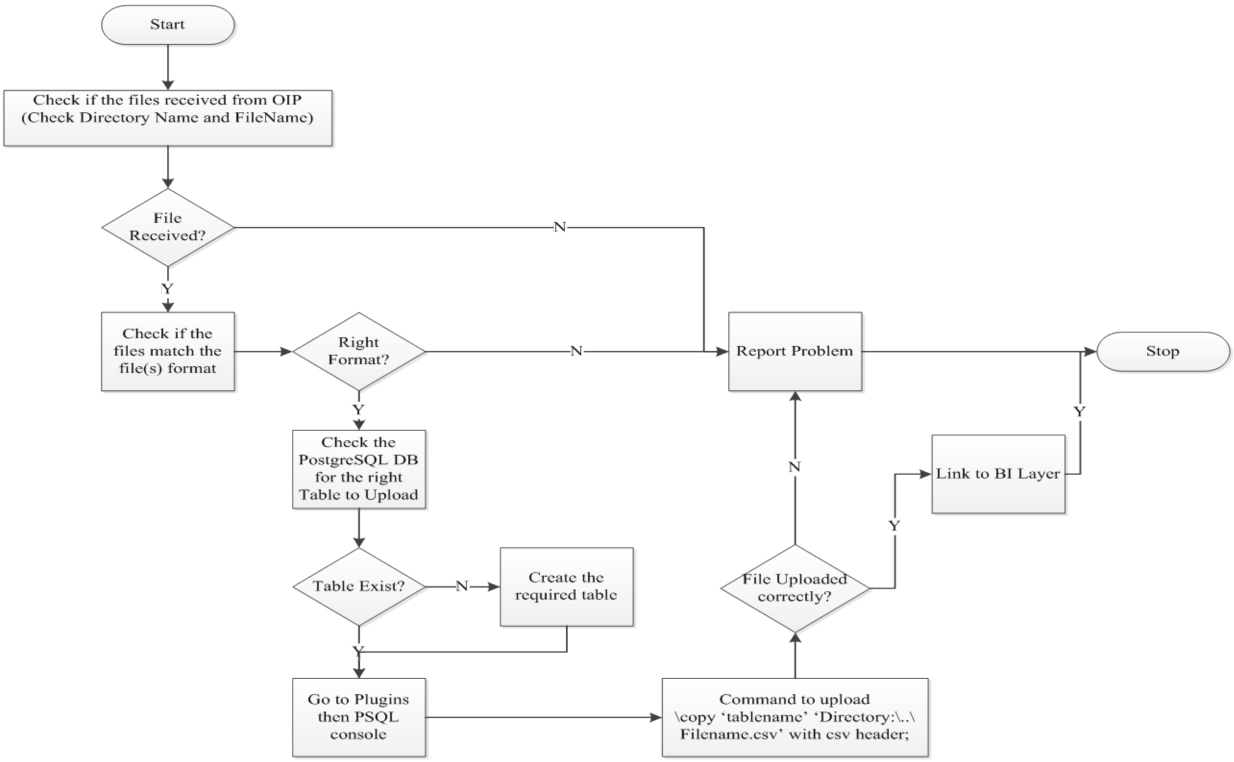



**Figure 43 – OIP Dashboard output from the Yellowfin BI platform**

### *OIP Database Definition*

| | |
|---|---|
| Name | OIP |
| Purpose | To store all information related to:<br>1) **Spatial layers:**<br>- Oyster Harvest Areas<br>- Aquaculture leases<br>- OISAS priority leases<br>- Macrophytes<br>- Land use types<br>- Flood mitigation (gates/ mgt)<br>- Sewer Lines/FloodMitDrains<br>- Acid Sulfate Soils (ASS)<br><br>2) **Temporal Information:**<br>- Water level/ Tidal level<br>- Microalgae/ Phytoplankton<br>- Bacteriological (water only)<br>- Rainfall<br>- Water quality (Physical, chemical and nutrients)<br>- Oyster production<br>- Dam (Tallowa) |
| Modification or New functionality | New functionality |
| Pre-conditions and parameters | OIP data provided from the following sources in the right format.<br>- NSW FA<br>- NSW DPI Fisheries<br>- NSW DPI<br>- SCC<br>- LPMA/LPI<br>- MHL/OeH<br>- BoM<br>- DECC and DEW (as Part of OzCoast)<br>- SCA |
| Post-conditions | |
| Qualify Criteria | As there are many different sources of data, separate document will detail the required quality criteria for each data source. |
| Circumstances of Use | The OIP database is used to report on Oyster Harvest Areas, Aquaculture leases, OISAS priority leases, Macrophytes, Land use types, Flood mitigation (gates/ mgt), Sewer Lines/FloodMitDrains, Acid Sulfate Soils (ASS), Water level/ Tidal level, Microalgae/ Phytoplankton, Bacteriological (water only), Rainfall, Water quality (Physical, chemical and nutrients), Oyster production, and Dam (Tallowa). |
| Basic Course | 1. OIP provides CSV/XLS files to SMART<br>2. The files uploaded into PostgesSQL (OIP Database) |

### *Manual Upload Process of OIP CSV files into PostgreSQL DB – Process Overview*



# Planned outcomes

A one size fits all strategy for adapting to climate change is not realistic for the industry as a whole, and therefore a single, current and scalable spatial-information source can provide the best tool for knowledge action and adaptive responses to change at local as well as national scales. This project has delivered a proof of concept of a spatially referenced web-mapping tool that collates existing natural resource and oyster industry data. This tool has been well received by the key end users such as oyster industry members and catchment managers, because users can now access a wide range of information that used to be stored in private storage units and that as a whole allows for a more integrated decision making process.

By having access to information hold in the OIP, industry users can now link oyster performance to environmental conditions and can change their husbandry practices to avoid non-optimal conditions. The OIP also can assist growers with informed advocacy for improved catchment management and improved industry management practices.

Similarly, governance stakeholders are now provided with a point of reference for industry relevant information that is linked to natural resources and catchment management. Access to the information contained in the OIP can assist them in: 1) better distributing information that catchment stakeholders have; 2) disseminate estuary health monitoring and reporting; 3) better access information of natural resource triggers for assisting with industry management frameworks (e.g. disease response, opening and closure of harvest areas); 4) monitor long-term water quality trends and evaluate success of catchment works; 5) help determining priority areas for NRM activities and programs; 6) provide evidence and justification for new projects and funding; 7) better prepare climate change adaptation strategies (e.g. identify borderline areas and new areas for production); and 8) as a resource tool to justify recommendations when deferred to for catchment development approvals processes.

# Project materials developed

This project developed an online and currently available Oyster Information Portal at www.oysterinformationportal.net.au, and is freely accessible. It has also been transferred to an accessible site through the University of Wollongong Dashboard concept as described above.

# References


Ajani, P., Brett, S., Krogh, M., Scanes, P., Webster, G. and Armand, L. (2012). *The risk of harmful algal blooms (HABs) in the oyster-growing estuaries of New South Wales, Australia.* Environmental Monitoring Assessment Accepted.

Aladaileh, S., S. V. Nair and D. A. Raftos (2007). "Induction of phenoloxidase and other immunological activities in Sydney rock oysters challenged with microbial pathogen-associate molecular patterns." Fish & Shellfish Immunology **23**(6): 1196-1208.

Aladaileh, S., S. V. Nair, D. Birch and D. A. Raftos (2007). "Sydney rock oyster (Saccostrea glomerata) hemocytes: Morphology and function." Journal of Invertebrate Pathology **96**(1): 48-63.

Anderson, T. J., R. D. Adlard and R. J. G. Lester (1995). "Molecular diagnosis of Marteilia sydneyi (Paramyxea) in Sydney rock oysters, Saccostrea commercialis (Angas)." Journal of Fish Diseases **18**(6): 507-510.

Appleyard, S. A. and R. D. Ward (2006). "Genetic diversity and effective population size in mass selection lines of Pacific oyster (Crassostrea gigas)." Aquaculture **254**(1-4): 148-159.

Banks, S. C., M. P. Piggott, D. A. Raftos and L. B. Beheregaray (2006). "Microsatellite markers for the Sydney rock oyster, Saccostrea glomerata, a commercially important bivalve in southeastern Australia." Molecular Ecology Notes **6**(3): 856-858.

Bezemer, B., D. Butt, J. Nell, R. Adlard and D. Raftos (2006). "Breeding for QX disease resistance negatively selects one form of the defensive enzyme, phenoloxidase, in Sydney rock oysters." Fish & Shellfish Immunology **20**(4): 627-636.

Butt, D. and D. Raftos (2007). "Immunosuppression in Sydney rock oysters (*Saccostrea glomerata*) and QX disease in the Hawkesbury River, Sydney " Marine and Freshwater Research **58**(2): 213-221.

Butt, D., K. Shaddick and D. Raftos (2006). "The effect of low salinity on phenoloxidase activity in the Sydney rock oyster, Saccostrea glomerata." Aquaculture **251**(2-4): 159-166.

Butt, D., S. Aladaileh, W. A. O'Connor and D. A. Raftos (2007). "Effect of starvation on biological factors related to immunological defence in the Sydney rock oyster (Saccostrea glomerata)." Aquaculture **264**(1-4): 82-91.

Butt, D., S. J. O'Connor, R. Kuchel, W. A. O'Connor and D. A. Raftos (2008). "Effects of the muscle relaxant, magnesium chloride, on the Sydney rock oyster (Saccostrea glomerata)." Aquaculture **275**(1-4): 342-346.

Coan, E. V., P. V. Scott and F. R. Bernard (2000). Bivalve Seashells of Western North America: Marine Bivalve Mollusks from Arctic Alaska to Baja California. Santa Barbara, Santa Barbara Museum of Natural History.

Cranford, P., Ward, J.E. and Shumway, S.E. (2011). *Bivalve filter feeding: variability and limits of the aquaculture biofilter. Shellfish Aquaculture and the Environment.* Shumway, S.E., Wiley-Blackwell**:** 81-124 pages.

DEC (2004). *Investing in our catchments: Water quality and its role in river health.* Technical Report produced for the Catchment Management Authorities. NSW Department of Environment and Conservation

Dove, M. C. and J. Sammut (2007). "Histological and feeding response of Sydney rock oysters, Saccostrea glomerata, to acid sulfate soil outflows." Journal of Shellfish Research **26**(2): 509-518.

Dove, M. C. and J. Sammut (2007). "Impacts of estuarine acidification on survival and growth of Sydney rock oysters Saccostrea Glomerata (gould 1850)." Journal of Shellfish Research **26**(2): 519-527.

Dove, M. C. and W. A. O'connor (2007). "Ecotoxicological evaluations of common hatchery substances and procedures used in the production of Sydney rock oysters Saccostrea glomerata (Gould 1850)." Journal of

Shellfish Research **26**(2): 501-508.

Dove, M. C. and W. A. O'connor (2007). "Salinity and temperature tolerance of Sydney rock oysters Saccostrea glomerata during early ontogeny." Journal of Shellfish Research **26**(4): 939-947.

EFSA (2010). "Scientific Opinion on the increased mortality events in Pacific oysters, *Crassostrea gigas*." EFSA Journal **8**(11): 1894.

English, L. J., G. B. Maguire and R. D. Ward (2000). "Genetic variation of wild and hatchery populations of the Pacific oyster, Crassostrea gigas (Thunberg), in Australia." Aquaculture **187**(3-4): 283-298.

Fleury, E., A. Huvet, C. Lelong, J. de Lorgeril, V. Boulo, Y. Gueguen, E. Bachere, A. Tanguy, D. Moraga, C. Fabioux, P. Lindeque, J. Shaw, R. Reinhardt, P. Prunet, G. Davey, S. Lapegue, C. Sauvage, C. Corporeau, J. Moal, F. Gavory, P. Wincker, F. Moreews, C. Klopp, M. Mathieu, P. Boudry and P. Favrel (2009). "Generation and analysis of a 29,745 unique Expressed Sequence Tags from the Pacific oyster (*Crassostrea gigas*) assembled into a publicly accessible database: the GigasDatabase." Bmc Genomics **10**.

Foighil, D. O. and D. J. Taylor (2000). "Evolution of parental care and ovulation behaviours in oysters." Molecular Phylogenetics and Evolution 15(2): 301-313.

Gaffney, P. (2006). "The role of genetics in shellfish restoration." Aquatic Living Resources **19**: 277-282.

Gjedrem, T. and M. Baranski (2009). Selective breeding in aquaculture: an introduction, Springer.

Gjedrem, T., N. Robinson and M. Rye (2012). "The importance of selective breeding in aquaculture to meet future demands for animal protein: A review." Aquaculture **350**(353): 117-129.

Green, T. J. and A. C. Barnes (2009). "Inhibitor of REL/NF-(K)B is regulated in Sydney rock oysters in response to specific double-stranded RNA and Vibrio alginolyticus, but the major immune anti-oxidants EcSOD and Prx6 are non-inducible." Fish & Shellfish Immunology **27**(2): 260-265.

Green, T. J. and A. C. Barnes (2010). "Bacterial diversity of the digestive gland of Sydney rock oysters, Saccostrea glomerata infected with the paramyxean parasite, Marteilia sydneyi." Journal of Applied Microbiology **109**(2): 613-622.

Green, T. J. and A. C. Barnes (2010). "Reduced salinity, but not estuarine acidification, is a cause of immune-suppression in the Sydney rock oyster Saccostrea glomerata." Marine Ecology-Progress Series **402**: 161-170.

Green, T. J., B. J. Jones, R. D. Adlard and A. C. Barnes (2008). "Parasites, pathological conditions and mortality in QX-resistant and wild-caught Sydney rock oysters, Saccostrea glomerata." Aquaculture **280**(1-4): 35-38.

Green, T. J., D. Raftos, W. O'Connor, R. D. Adlard and A. C. Barnes (2011). "Disease Prevention Strategies for Qx Disease (Marteilia Sydneyi) of Sydney Rock Oysters (Saccostrea Glomerata)." Journal of Shellfish Research **30**(1): 47-53.

Green, T. J., T. J. Dixon, E. Devic, R. D. Adlard and A. C. Barnes (2009). "Differential expression of genes encoding anti-oxidant enzymes in Sydney rock oysters, Saccostrea glomerata (Gould) selected for disease resistance." Fish & Shellfish Immunology **26**(5): 799-810.

Guo, X. (2009). "Use and exchange of genetic resources in molluscan aquaculture." Reviews in Aquaculture **1**: 251-259.

Guo, X., G. A. DeBrosse and S. K. Allen Jr (1996). "All-triploid Pacific oysters (*Crassostrea gigas* Thunberg) produced by mating tetraploids and diploids." Aquaculture 142(3–4): 149-161.

Gwak, W. S. and K. Nakayama (2011). "Genetic variation of hatchery and wild stocks of the pearl oyster Pinctada fucata martensii (Dunker, 1872), assessed by mitochondrial DNA analysis." Aquaculture

International **19**(3): 585-591.

Hand, R. E., J. A. Nell and P. A. Thompson (2004). "Studies on triploid oysters in Australia XIII. Performance of diploid and triploid Sydney rock oyster, Saccostrea glomerata (Gould, 1850), progeny from a third generation breeding line." Aquaculture **233**(1-4): 93-107.

Hedgecock, D. (2011). Genetics of Shellfish on a Human-Dominated Planet. Shellfish Aquaculture and the Environment. S. E. Shumway. Oxford, Wiley-Blackwell.

Hewitt, C. L. and M. L. Campbell (2007). "Mechanisms for the prevention of marine bioinvasions for better biosecurity." Marine Pollution Bulletin 55(7–9): 395-401.

Hook, L.A., K.S.V, S., Beaty, T., Cook, R. and Wilson, B. (2010). Best Practices for Preparing Environmental Data Sets to Share and Archive. Available online (http://daac.ornl.gov/PI/BestPractices-2010.pdf) from Oak Ridge National Laboratory Distributed Active Archive Center Oak Ridge, Tennessee, U.S.A,

Hurwood, D. A., M. P. Heasman and P. B. Mather (2005). "Gene flow, colonisation and demographic history of the flat oyster Ostrea angasi." Marine and Freshwater Research **56**(8): 1099-1106.

Huvety, A., J. Norman, E. Fleury, V. Quillien, C. Fabioux and P. Boudry (2010). "Aquaculture Reproductive effort of Pacific oysters: A trait associated with susceptibility to Summer Mortality." Aquaculture **304**: 95-99.

Kardamanidis, K., S. J. Corbett and A. P. Zammitt (2009). "Hepatitis A: Wallis Lake revisited." New South Wales Public Health Bulletin **20**(2): 29-30.

Kirkendale, L., P. C. Winberg, A. R. Rubio and P. Middelfart (2013). "Taking stock of genetic resources for the Australian oyster industry; risks and hidden opportunity." Reviews in Aquaculture under review.

Kleeman, S. N. and R. D. Adlard (2000). "Molecular detection of Marteilia sydneyi, pathogen of Sydney rock oysters." Diseases of Aquatic Organisms **40**(2): 137-146.

Lallias, D., A. R. Beaumont, C. S. Haley, P. Boudry, S. Heurtebise and S. Lapegue (2007). "A first-generation genetic linkage map of the European flat oyster Ostrea edulis (L.) based on AFLP and microsatellite markers." Animal Genetics **38**(6): 560-568.

Lallias, D., R. Stockdale, P. Boudry, A. R. Beaumont and S. Lapegue (2009). "Characterization of 27 microsatellite loci in the European flat oyster Ostrea edulis." Molecular Ecology Resources **9**(3): 960-963.

Lam, K. and B. Morton (2006). "Morphological and mitochondrial-DNA analysis of the Indo-West Pacific rock oysters (Ostreidae : Saccostrea species)." Journal of Molluscan Studies **72**: 235-245.

Lazoski, C., J. Gusmao, P. Boudry and A. M. Sole-Cava (2011). "Phylogeny and phylogeography of Atlantic oyster species: evolutionary history, limited genetic connectivity and isolation by distance." Marine Ecology-Progress Series **426**: 197-212.

Leith, P.B. and Haward, M. (2010). Climate Change Adaptation in the Australian Edible Oyster Industry: an analysis of policy and practice. University of Tasmania Hobart, Tasmania, Australia.http://arnmbr.org/content/images/uploads/OYSTER_REPORT_FINAL_web.pdf

Lemer, S., E. Rochel and S. Planes (2011). "Correction Method for Null Alleles in Species with Variable Microsatellite Flanking Regions, A Case Study of the Black-Lipped Pearl Oyster Pinctada margaritifera." Journal of Heredity **102**(2): 243-246.

Liu, J. U. N., Q. I. Li, L. Kong, H. Yu and X. Zheng (2011). "- Identifying the true oysters (Bivalvia: Ostreidae) with mitochondrial phylogeny and distance-based DNA barcoding." **- 11**(- 5): - 830.

Mackintosh, K., C. Dang, A. Barnes and T. Green (2011). "Effect of in-Vitro Pesticide Exposure on Oxidative Burst Potential of Sydney Rock Oyster Hemocytes." Journal of Shellfish Research **30**(2): 529-529.

Maguire, G. B., N. C. Gardner, J. A. Nell, G. N. Kent and A. S. Kent (1995). "Studies on triploid oysters in

Australia .2. Growth, condition index gonad area, and glycogen content of triploid and diploid Pacific oysters, Crassostrea gigas, from oyster leases in Tasmania, Australia." Aquaculture **137**(1-4): 357-357.

Melo, C. M. R., F. C. Silva, C. Gomes, A. M. Sole-Cava and C. Lazoski (2010). "Crassostrea gigas in natural oyster banks in southern Brazil." Biological Invasions **12**(3): 441-449.

Meyer, B. J. (2003). "Dietary intakes and food sources of omega-6 and omega-3 polyunsaturated fatty acids." Lipids 38: 391-398.

Miller, P. (2012). "Diversity of Crassostrea gigas in Australia: A comparison between farmed and wild diversity." Journal of Shellfish Research **(in press)**.

Moon, M. J. (2002). "The Evolution of E-Government among Municipalities: Rhetoric or Reality?" Public Administration Review **62**(4): 424-433.

Nash, C. and Rubio, A. (2012). *Monitoring the canaries of our catchments.* 2012 NSW Coastal Conference, Kiama, NSW, Australia

Nell, J. A. (2001). "The history of oyster farming in Australia." Marine Fisheries Review **16**(3): 14-25.

Nell, J. A. and B. Perkins (2005). "Evaluation of progeny of fourth generation Sydney rock oyster Saccostrea glomerata (Gould, 1850) breeding lines." Aquaculture Research **36**(8): 753-757.

Nell, J. A. and B. Perkins (2006). "Evaluation of the progeny of third-generation Sydney rock oyster Saccostrea glomerata (Gould, 1850) breeding lines for resistance to QX disease Marteilia sydneyi and winter mortality Bonamia roughleyi." Aquaculture Research **37**(7): 693-700.

Nell, J. A. and R. E. Hand (2003). "Evaluation of the progeny of second-generation Sydney rock oyster Saccostrea glomerata (Gould, 1850) breeding lines for resistance to QX disease Marteilia sydneyi." Aquaculture **228**(1-4): 27-35.

Nell, J. A., A. K. Sheridan and I. R. Smith (1996). "Progress in a Sydney rock oyster, Saccostrea commercialis (Iredale and Roughley), breeding program." Aquaculture **144**(4): 295-302.

Nell, J. A., E. Cox, I. R. Smith and G. B. Maguire (1994). "Studies on Triploid Oysters in Australia .1. The Farming Potential of Triploid Sydney Rock Oysters Saccostrea-Commercialis (Iredale and Roughley)." Aquaculture **126**(3-4): 243-255.

Newton, K., R. Peters and D. Raftos (2004). "Phenoloxidase and QX disease resistance in Sydney rock oysters (Saccostrea glomerata)." Developmental and Comparative Immunology **28**(6): 565-569.

NSW Department of Primary Industries (2006). The NSW Oyster Industry- Sustainable Aquaculture Strategy. NSW Department of Primary Industries, Port Stephens Fisheries Centre, Taylors Beach, NSW, 66 pages.http://fisheries.nsw.gov.au

NSW DPI (2011). Aquaculture Production Report 2010-2011. NSW Department of Primary Industries. Aquaculture Unit, Port Stephens Fisheries Institute.http://www.dpi.nsw.gov.au

NSW DPI (2013). Hawkesbury River oysters under the microscope. Media Release. http://www.dpi.nsw.gov.au/aboutus/news/all/2013/hawkesbury-river-oysters-under-the-microscope, NSW Department of Primary Industries.

O'Connor, W.A. and Dove, M.C. (2009). *The changing face of oyster culture in New South Wales, Australia.* Journal of Shellfish Research 28 (4): 803-811.

OZCAM, Ed. (2012). Online Zoological Collections of Australian Museums. http://www.ozcam.org.au.

Parker, L. M., P. M. Ross and W. A. O'Connor (2009). "The effect of ocean acidification and temperature on the fertilization and embryonic development of the Sydney rock oyster Saccostrea glomerata (Gould 1850)." Global Change Biology **15**(9): 2123-2136.

Parker, L. M., P. M. Ross and W. A. O'Connor (2010). "Comparing the effect of elevated pCO(2) and temperature on the fertilization and early development of two species of oysters." Marine Biology **157**(11): 2435-2452.

Parker, L. M., P. M. Ross and W. A. O'Connor (2011). "Populations of the Sydney rock oyster, Saccostrea glomerata, vary in response to ocean acidification." Marine Biology **158**(3): 689-697.

Peters, R. and D. A. Raftos (2003). "The role of phenoloxidase suppression in QX disease outbreaks among Sydney rock oysters (Saccostrea glomerata)." Aquaculture **223**(1-4): 29-39.

Plough, L. V. (2012). "Environmental stress increases selection against and dominance of deleterious mutations in inbred families of the Pacific oyster *Crassostrea gigas*." Molecular Ecology **21**(16): 3974-3987.

Ponzoni, R. W., N. H. Nguyen, H. L. Khaw and B. M. Rodriguez Jr. (2012). "Considerations about effective dissemination of improved fish strains." WorldFish, Penang, Malaysia. **Working Paper 2012-47.**

Rubio, A. (2008). *The dynamics and distribution of food supplies for the Sydney rock oyster (Saccostrea glomerata) in southern NSW estuaries. 2004/224 Technical Report for Fisheries Research and Development Corporation,*

Rubio, A., I. Paul-Pont, R. Whittington, P. C. Winberg, H. Davies, P. Coad, A. R. Davis, L. Kirkendale, R. Warner, Broken Bay Oyster Association, Merimbula Oyster Growers, Pambula Oyster Growers and Shoalhaven Oyster growers (2012). An innovative program to monitor oyster and estuarine health. Australasian Aquaculture 2012. Melbourne.

Rubio, A., P. Winberg, L. Kirkendale, R. Warner and A. R. Davis (2013). Ensuring that the Australian Oyster Industry adapts to a changing climate: a natural resource and industry spatial information portal for knowledge action and informed adaptation frameworks (OYSTER INFORMATION PORTAL). Project No. 2011/534. Fisheries Research & Development Corporation. Canberra, Australia. in press.

Schlesselman, G. W. (1955). "The Gulf Coast Oyster Industry of the United States." Geographical Review **45**(4): 531-541.

Shumway, S.E. (2011). *Shellfish aquaculture and the environment*, First Edition,. Wiley-Blackwell, John Wiley & Sons, Inc. 639 Pages.

Simms, A.D. and Woodroffe, C. (2008). *Scoping Study of Climate Change in the Southern Rivers Region: Focus on Natural, Built, Coastal and Marine Systems. Wollongong: Southern Rivers Catchment Management Authority*, . GeoQuEST Research Centre, School of Earth and Environmental Sciences, University of Wollongong NSW, Australia

Simonian, M., S. V. Nair, J. A. Nell and D. A. Raftos (2009). "Proteomic clues to the identification of QX disease-resistance biomarkers in selectively bred Sydney rock oysters, Saccostrea glomerata." Journal of Proteomics **73**(2): 209-217.

Simonian, M., S. V. Nair, W. A. O'Connor and D. A. Raftos (2009). "Protein markers of Marteilia sydneyi infection in Sydney rock oysters, Saccostrea glomerata." Journal of Fish Diseases **32**(4): 367-375.

Smith, I. R., J. A. Nell and R. Adlard (2000). "The effect of growing level and growing method on winter mortality, Mikrocytos roughleyi, in diploid and triploid Sydney rock oysters, Saccostrea glomerata." Aquaculture **185**(3-4): 197-205.

Stick, D. A., C. J. Langdon, M. A. Banks and M. D. Camara (2009). "Nineteen novel microsatellite markers for the Olympia oyster, Ostrea conchaphila/lurida." Molecular Ecology Resources **9**(1): 153-155.

Summerhayes, S. A., B. P. Kelaher and M. J. Bishop (2009). "Spatial Patterns of Wild Oysters in the Hawkesbury River, Nsw, Australia." Journal of Shellfish Research **28**(3): 447-451.

Tester, P. A. (1994). "Harmful marine Phytoplankton and shellfish toxicity; potential consequences of climate change." Annals of the New York Academy of Sciences **740**: 69-76.

The Climate Commission (2011). The Critical Decade: New South Wales climate impacts and opportunities. A report produced by The Climate Commission.www.climatecommission.gov.au/wp-content/uploads/NSW-report_final_web.pdf

Thompson, E. L., D. A. Taylor, S. V. Nair, G. Birch, P. A. Haynes and D. A. Raftos (2011). "A proteomic analysis of the effects of metal contamination on Sydney Rock Oyster (Saccostrea glomerata) haemolymph." Aquatic Toxicology **103**(3-4): 241-249.

Thomson, J. M. (1952). "The acclimatization and growth of the Pacific Oyster (*Gryphaea gigas*) in Australia." Marine and Freshwater Research **3**(1): 64-73.

Thomson, J. M. (1959). "The naturalization of the Pacific Oyster in Australia." Marine and Freshwater Research **10**(2): 144-149.

Trainer, V.L., Bates, S.S., Lundholm, N., Thessen, A.E., Cochlan, W.P., Adams, N.G. and et al. (2012). *Pseudo-nitzschia physiological ecology, phylogeny, toxicity, monitoring and impacts on ecosystem health.* Harmful Algae 14: 271-300.

Tynan, R., K. Bunter and W. O'Connor (2010). Industry management and commercialisation of the Sydney Rock Oyster Breeding Program. Port Stephens, Industry and Investment NSW Fisheries. **Project No. 2005/209**.

Wang, H. Y., X. M. Guo, G. F. Zhang and F. S. Zhang (2004). "Classification of jinjiang oysters Crassostrea rivularis (Gould, 1861) from China, based on morphology and phylogenetic analysis." Aquaculture **242**(1-4): 137-155.

Wang, Y., X. X. Wang, A. M. Wang and X. M. Guo (2010). "A 16-microsatellite multiplex assay for parentage assignment in the eastern oyster (Crassostrea virginica Gmelin)." Aquaculture **308**: S28-S33.

Watson, S. A., P. C. Southgate, P. A. Tyler and L. S. Peck (2009). "Early Larval Development of the Sydney Rock Oyster Saccostrea Glomerata under near-Future Predictions of Co(2)-Driven Ocean Acidification." Journal of Shellfish Research **28**(3): 431-437.

White, I. (2001). Safeguarding environmental conditions for oyster cultivation in New South Wales. Report to Healthy Rivers Commission Centre for Resource and Environmental Studies, Australian National University, 84 pages.http://www.hrc.nsw.gov.au/site/pdf/reports/oysters_final.pdf

Winberg, P., A. R. Rubio and L. K. Kirkendale (2012). Climate Change & Marine Living Resources. Climate Change and the Oceans: Gauging the Legal and Policy Currents in the Asia Pacific and Beyond. R. Warner, M. Tsamenyi and C. Schofield. Cheltenham, UK, Edward Elgar Publishing Ltd.

WORMS (2012). World Register of Marine Species. W. Appeltans, P. Bouchet, G. A. Boxshallet al. http://www.marinespecies.org.

Xia, J. J., X. C. He and Z. N. Yu (2009). "Isolation and characterization of fourteen novel microsatellite loci in the Hong Kong oyster, Crassostrea hongkongensis." Conservation Genetics **10**(6): 1829-1832.

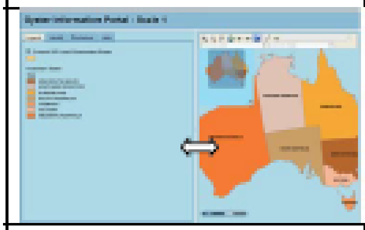
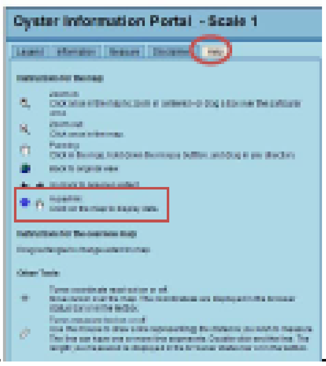
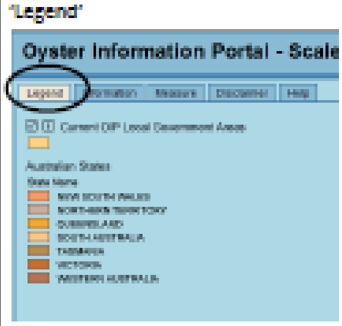
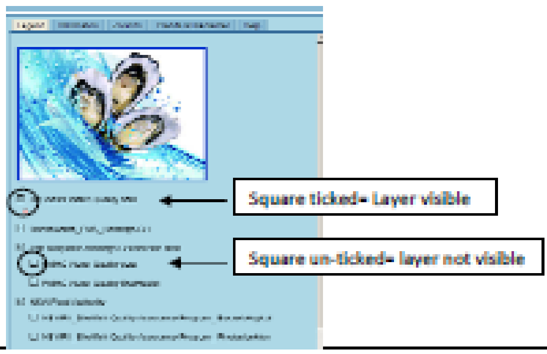
Xiao, J., J. F. Cordes, J. A. Moss and K. S. Reece (2011). "Genetic diversity in US hatchery stocks of *crassostrea ariakensis (fujita, 1913)* and comparison with natural populations in Asia." Journal of Shellfish Research **30**(3): 751-760.

Yu, H., Q. Li and R. H. Yu (2008). "Genetic differentiation between Zhe oyster Crassostrea plicatula and Pacific oyster Crassostrea gigas populations in China assessed by microsatellite analysis." Fisheries Science **74**(1): 88-97.

Zhang, L. S. and X. M. Guo (2010). "Development and validation of single nucleotide polymorphism markers in the eastern oyster Crassostrea virginica Gmelin by mining ESTs and resequencing." Aquaculture **302**(1-2): 124-129.

# Appendix I: Data Portal User-guide

Below are some screen shots of the OIP user guide which can be downloaded in full from the [www.oysterinformationportal.net.au](http://www.oysterinformationportal.net.au)

| | |
|---|---|
| http://www.oysterinformationportal.net.au/data-portal | |
| **Oyster Information Portal (Scale 1)= Australia and NSW LGA scale** | |
| **General tools:** | Most of the tools used in this web-mapping tool are similar to the tools you use in web and GIS softwares |
|  | Enlarge 'Map' or 'Legend' window:<br>You can place mouse on margin separating both windows- you will see that the mouse pointer changes to an arrow with both points- left click mouse and while holding left click, drag mouse so that the margin moves based on the window you would like to enlarge |
| Check the 'Help' tab<br> | Please familiarise at this scale with the tools for Zoom in; Zoom out; Panning; Back to original view (useful for when you have zoom in too much and you are not sure where you are in the overall map).<br><br>You will need to use the  Hyperlink (shown in red rectangular) to extract information from the different layers/ polygons or points. The information associated with the feature you have selected will come up in the 'Information' tab. See more information on this below under the 'Information' tab. |
| 'Legend'<br> | The 'Legend' tab will show the layers of information that the map holds at any scale.<br>In some cases the layers will always be shown as in Scale 1 (diagram on the left) and in other cases each layer will have a square in front of the name of the layer that will allow you to switch them on (by ticking the square, so the map draws the information from this layer) or switch them off (by un-ticking the square so the information is not displayed in the map- see below).<br> |

<table>
<tr>
<td>You have two options in Scale-1 to 'Zoom to' using the drop-down arrows on the top of the map area. You can Zoom to <u>LGA</u> or you can Zoom to a <u>State</u>.<br><br>LGA= Local Government Area. Remember that in this prototype we have been working in 4 LGAs (Port Macquarie/Hastings; Lower Hawkesbury; Shoalhaven and Bega with focus on Pambula Lake)</td>
<td><br></td>
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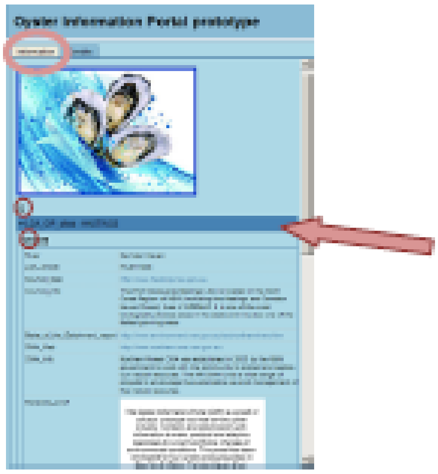
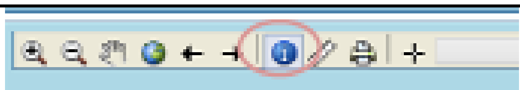
<tr>
<td>'Information' tab<br><br></td>
<td><br>Click on the  icon and then click on a feature on the map (e.g. click somewhere on NSW state or one of the NSW LGAs). => A new window will be populated under the 'Information' tab. You can scroll down to read about the information provided and clink on the plots/ images to visualise them at a larger scale (more details on how to do this below).<br>You can open more than one Hyperlink per map. Each hyperlink will result in a different window that will be collated like an accordion in the 'Information' tab. By clicking on the name of a window, this will collapse or extend accordingly.<br>If you have opened too many Information tabs and you would like to close them all and start from scratch- please tick the small square with the 'x' in it- it will clear all windows that are opened or it will clear the window you have selected</td>
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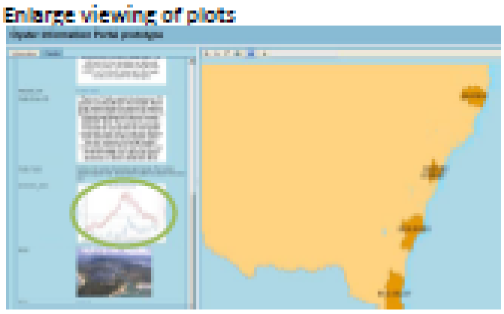
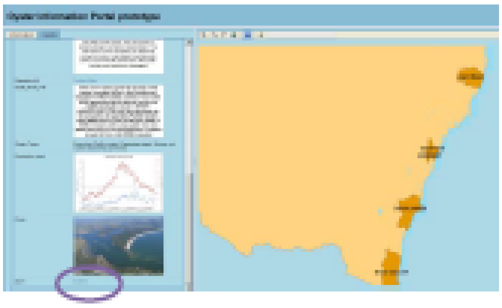
<tr>
<td>Enlarge viewing of plots<br><br><br></td>
<td>Enlarge photos, plots or other graphics.<br>1 Large scale images appear in <u>NEW front Window:</u> Click on image and the image will be displayed larger on your screen. To close image, press the 'x' button on the bottom of the image (if this does not work, then press 'Esc')<br>2 If you right-click on the image you can then 'Copy' or 'Save as' so you can paste them in word if you would like to compare different plots from different regions<br>[In this version of the portal we do not have an option to compare side-by-side plots as we did in some industry workshops]<br><br>Equally you can click on any external web link shown from the Information window</td>
</tr>
</table>

## Oyster Information Portal (Scale 2)= Specific River information

### Zoom to Scale 2- River scale

How to Zoom from LGA to River scale:

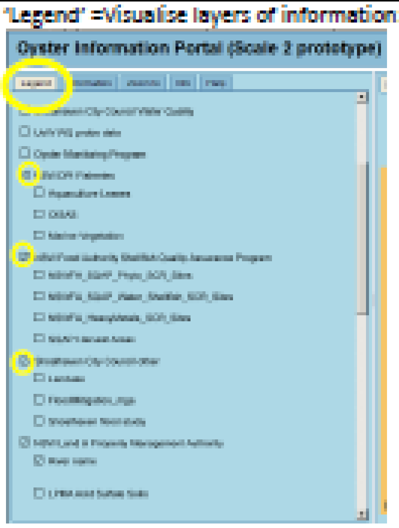


If you scroll to the end of the page from the LGA window there is an entry to Zoom to a 'Scale 2 River name'. If you click on this link a second web browser tab will be opened with the "River scale map" you have selected. Depending on your computer set-up, this second browser could open in a new window or a new tab. If you want to have different tabs/windows for each Scale-2 map for each river, please right click on the 'Zoom to Scale 2' hyperlink at the bottom of the page and select 'Open in new tab' or 'Open in new window'

Currently there are 4x Scale 2 maps developed – one for each OIP oyster river (Camden, Hawkesbury, Shoalhaven, and Pambula).

When working on this scale map, please do not use the back arrow to go back or your map will re-appear blank with none of the selections you have been working on.

'Legend' =Visualise layers of information:




As you open a new map, no layer of information will be selected. You need to click and unclick the squares for each layer of information as you wish to visualise the information. You can overlay layers of information by clicking on several layers. These layers are organised so that a top layer will lay on top of a bottom layer (i.e as if you are making a cake or lasagna!). This means that layers on top will hide/overlay information from layers below.

If you cannot see one layer of information might be because another layer could be covering the area that you have selected or you might not have clicked that layer to be visualised from the 'Legend' tab.

From here you can select information from features on the map (sampling points, polygons, areas) by using the  Hyperlink icon. Information windows for each selectable point will appear in the Information tab as per Scale 1.

A table summarising data information by custodian used in this data portal has been included at the end of this user-guide. This table also includes a list of acronyms used in this portal.

# Appendix II: Research Staff on project

**Dr Pia Winberg -** from the Shoalhaven Marine and Freshwater Centre at the University of Wollongong. Pia has extensive research experience in estuarine ecology and in sustainable, integrated aquaculture systems. Pia has been involved in both natural resource monitoring programs with local government, water authorities and marine parks, undertaken research on nutrient dynamics in coastal systems, and applied this knowledge in developing sustainable aquaculture system modules.

**Dr Ana Rubio -** from the Shoalhaven Marine and Freshwater Centre at the University of Wollongong. Her work combines environment, health of catchments and waterways and aquaculture industry practices. For the last 10 years she has worked mainly with the Australian oyster industry establishing strong research relationship with the industry nationally, and particularly in NSW. Ana has a thorough understanding about what the important links between natural resource variables and the oyster industry are. Ana has a practical understanding of industry operations and needs.

**Dr Lisa Kirkendale -** from the Shoalhaven Marine and Freshwater Centre at the University of Wollongong. Lisa is a marine ecologist with expertise in molluscan (in particular oyster species) phylogenetics, evolution and biogeography and has worked in Canada, USA and Micronesia. Lisa's research applies molecular phylogenies of molluscan systems to biogeographic questions, invertebrate biodiversity and application of this knowledge to topically and regionally relevant issues, including conservation, species management, identification of introduced species and indications of global change.

**Assoc Prof Andrew Davis -** from the Institute for Conservation Biology and Environmental Management at the University of Wollongong. Andrew's research interest includes invertebrate ecology, bio-geographic patterns and determinants of biodiversity, with extensive experience working with molluscs.

# Appendix III: Steering Committee Members

The Oyster Information Portal has been developed with the support, guidance, and knowledge from our steering committee members. The steering committee of this project is formed by representatives of the following organizations:

- NSW Food Authority, Grant Webster and Anthony Zammit
- Office of Environment and Heritage, Tony Roper
- Northern Rivers Catchment Management Authority, Max Osborne
- Southern Rivers Catchment Management Authority, Adam Gietzelt and Martine Frazer
- University of Tasmania, Peat Leith
- Port Macquarie Hastings Council, Thor Aaso
- Hornsby Shire Council, Peter Coad
- Shoalhaven City Council, Isabelle Ghetti
- Bega Valley Shire Council, Derek van Bracht

# Appendix IV: Stakeholder List

| Organisation | Contact |
|---|---|
| AIMS | Mark Rehbein |
| AODN-IMOS | Jacqui Hope |
| Atlas of Living Australia | Owen Butler |
| Ballina council | Suzanne Acret |
| Bega Valley Shire Council | Derek van Bracht |
| Bega Valley Shire Council | Daniel Madigan |
| Bureau of Meteorology | Richard Mount |
| Bureau of Meteorology | Ian McVay |
| Consultant | Shane Comiskey |
| CSIRO | Peter Brenton |
| CSIRO | Jonathan Hodge |
| CSIRO Coastal Portal | Toni Cannard |
| CSIRO Coastal Portal | Chantelle Agha-Hamilton |
| DPI Vic | John Mercer |
| Eurobodalla Shire Council | Deb Lenson |
| FRDC | Colin Creighton |
| Gosford City Council | Tim Macdonald |
| Hornsby Shire Council | Ross MacPherson |
| Hornsby Shire Council | Peter Coad |
| IMOS | Roger Proctor |
| IMOS | Katy Hill |
| Macquarie University | Penny Ajani |
| METOC | Andrew Walsh |
| Northern Rivers CMA | Dr Annette Harrison |
| Northern Rivers CMA | Mark Asquith |
| Northern Rivers CMA | Peter Boyd |
| Northern Rivers CMA | Ian Simpson |
| Northern Rivers CMA | Max Osborne |
| NSW DPI Aquatic Ecosystems | Bob Creese |
| NSW DPI Aquatic Ecosystems | Tim Glasby |
| NSW DPI Aquatic Ecosystems | Greg West |
| NSW DPI Fisheries | Wayne O'connor |
| NSW DPI Fisheries | Mike Dove |
| NSW DPI Fisheries | Ian Lyall |
| NSW DPI Fisheries | Tim Gippel |
| NSW DPI Fisheries | Steve Mc'Orrie |
| | |

| Organisation | Contact |
|---|---|
| NSW Food Authority | Grant Webster |
| NSW Food Authority | Anthony Sammit |
| NSW Food Authority | Melanie Field |
| NSW Food Authority | Grant Webster |
| Oceanwatch Australia | Simon Rowe |
| Oceanwatch Australia | Andy Myers |
| Oceanwatch Australia | Michael Woodie |
| Oceanwatch Australia | Lowri Price |
| OEH | Tim Pritchard |
| OEH | John Schmidt |
| OEH | Tony Roper |
| OEH | Kerryn Stephens |
| Office of Spatial Policy, Department of Resources, Energy and Tourism | Margaret Smith and John Weaver |
| Oysters Australia | Rachel King |
| Oysters QLD | Jane Clout |
| Oysters TAS | Tom Lewis |
| PIRSA | Steve Clarke |
| Port Macquarie Hastings Council | Thor Asso |
| QLD- biosecurity | Tim Green |
| QLD- biosecurity | Marissa McNamara |
| QLD- biosecurity (portal) | Marissa McNamara |
| RET (DEPT) Resources Energy and Tourism | John Hockaday |
| SA Oysters Growers Association | Trudy McGowan |
| Shoalhaven City Council | Isabelle Ghetti |
| Shoalhaven City Council | Kelie Lowe /Ray Massie |
| South East Program | Dallas D'Silva |
| South East Program | Daniel Spooner |
| Southern Rivers CMA | Chris Presland |
| Southern Rivers CMA | Adam Gietzel |
| Southern Rivers CMA | Jillian Keating |
| Southern Rivers CMA | Helen Davies |
| Southern Rivers CMA | Martine Frazer |
| Tasmanian Oyster Research Committee | Bob Cox |
| CSIRO- Coastal TERN facility | Andy Steven |
| TERN | Alex Held |
| TERN | Ed King |
| + NSW, SA, TAS and QLD growers | |