# Linking ecosystem services to the profitability of prawn fisheries

## Final report

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Linking ecosystem services to the profitability of prawn fisheries

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

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# Acknowledgements

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# Executive summary

This final report summarises the results of FRDC Project 2017-175 *Linking ecosystem services to the profitability of prawn fisheries*, which delivered new methods, data and indicators to a case study on prawn fisheries in the broader project entitled *Lifting farm gate profits: the role of natural capital accounts* (RnD4Profit-16-03-003). The FRDC project allowed us to collect new primary data to supplement other publically available datasets, and to more fully engage with stakeholders locally.

## Background

Natural capital is the stock of renewable and non-renewable resources – such as soil, water, plants, animals, minerals and air – on which primary industries rely to produce food and fibre for society. Natural capital accounting brings together environmental and economic information, so that businesses and stakeholders can assess the risks and opportunities associated with natural capital. This linkage with economic accounts offers benefits beyond certification.

This project was part of a broader project *Lifting farm gate profits: the role of natural capital accounts,* which sought to determine whether natural capital accounting could support decision making and drive better productivity across three primary industries: cotton, fisheries and forestry. The FRDC Project 2017-175 contributed to the fisheries case study by:

- compiling data for experimental natural capital accounts
- identifying, interviewing and engaging stakeholders
- providing input and feedback on results and outputs from the broader project.

## Objectives

The objectives of the FRDC Project 2017-175 were to:

1. Link the profitability of prawn fisheries in NSW to the ecosystem services provided by natural assets

2. Identify and engage stakeholders related to prawn fisheries in NSW

3. Increase stakeholders' awareness of and skills in natural capital accounting

## Methods

We aimed to provide a comprehensive approach that could be applied to any estuarine fishery in Australia, using the Wallis Lake prawn fishery as a case study. Initially, we consulted with stakeholders from diverse backgrounds including academia, commercial and recreational fisheries, government, and non-governmental agencies to determine their understanding of natural capital accounts and how they believed they might be useful for commercial fisheries, as well as their knowledge of this specific fishery. Then, we designed a conceptual model of the Wallis Lake prawn fishery using known science and feedback from local stakeholders. This project was designed to fill one key data gap by primary collection of samples of prawns and vegetation; undertaking isotope analysis; and then using stable isotope modelling to estimate the economic value of habitats that support the diets of economically important species of fish and prawns. Finally, we combined known information on the assets identified in the system with our ecological understanding of the system to build experimental natural capital accounts for the prawn fishery in Wallis Lake.

## Results

### *Biophysical modelling*

One of the principal drivers of fisheries productivity is the biological primary production by estuarine habitats (mangroves, saltmarsh, seagrass). This project filled a significant key data gap by estimating the economic value of habitats that support the diets of economically important species of fish and prawns.

Estuarine habitat valuation using stable-isotope derived primary producer contribution to diet suggests that saltmarshes had the highest value for prawn fisheries in Wallis Lake, followed by seagrasses and mangroves (Figure 5). Including all species, the per hectare value of saltmarshes was highest at approximately AUD \$600 $ha^{-1}$ $yr^{-1}$, while the low areal coverage of mangroves had a relative contribution of approximately AUD \$230 $ha^{-1}$ $yr^{-1}$. This suggests that the rehabilitation of mangroves and saltmarshes should be prioritised in Wallis Lake to promote fisheries productivity, while underlining that seagrasses are also important in the system, providing food and habitat resources for a range of species.

### *Natural capital accounting*

The project interviewed stakeholders to better understand the value proposition for natural capital accounting in the prawn-fishing industry. While the individual information needs of stakeholders differed, all recognised the benefits of reliable knowledge of ecosystem function and processes. Stakeholders prioritised the following major activities and events for natural capital accounting:

- freshwater pulses
- agriculture
- commercial fisheries.

These priorities guided the selection of the following natural capital accounts, which were compiled by the broader project:

- precipitation in the catchment
- freshwater pulses in the catchment
- land use in the catchment
- terrestrial and riparian vegetation in the catchment
- aquatic prawn habitat
- water quality in the prawn habitat
- landed prawn biomass in the fishable area.

Experimental natural capital accounts (Table 1) suggest that the value of habitats in Wallis Lake for the prawn fishery can change significantly over the years. This highlights the interrelationship between contribution to diet of prawn from these habitats, areal extent of estuarine habitats, and total value of prawn landings in a given year.

## Implications

Our project demonstrates the steps required to produce natural capital accounts for commercial fisheries. Through stakeholder engagement, we identified that the approach was valuable for not only fisheries, but also of great interest to local stakeholders in both government and the public. Stakeholders agreed the approach would be useful for supporting targeted rehabilitation within estuarine systems given the inextricable link between habitats, productivity and profitability.

The future availability of regularly updated information is an important consideration for stakeholders who want to implement and operationalise these natural capital accounts. It is important to identify who might be best placed to operationalise ongoing natural capital accounts. Our stakeholder engagement revealed that small-scale fishery enterprises are unlikely to develop natural capital accounts by themselves without significant help. This suggests that a different organisation is better placed to develop the natural capital accounts, potentially a local or state government; or consultants commissioned jointly by several industries that share the resources of the estuary; or a research agency or peak body tasked with supporting the viability of local industries.

## Recommendations

### *Natural capital accounting*

1. The study showed that to be of greatest use there is need to broaden the number of accounts prepared to cover all uses of the estuary, not just those primarily related to the fishery. Additional accounts would be required to cover all ecosystem services that occur in the estuary

(for example, carbon sequestration, recreational fishing, other fisheries not considered here, and offshore fisheries that may derive productivity from the estuary).

2. To improve the usefulness of the environmental-economic valuation of the fishery, future studies would benefit from development of new methods to value non-dietary aspects of the habitat, such as nursery use, shelter from predation, and reproduction.
3. To extend the usefulness of the approach, it is recommended to expand the conceptual model and natural capital accounts to consider all interdependencies that occur within and immediately outside the estuary system not just those related to the fishery (e.g. climate change, development due to growing population).
4. To provide management-relevant accounts it would be necessary to collect more finely resolved temporal data (e.g. on freshwater pulses and changes to habitats), as this would enhance our ability to predict how changes in the landscape and ecosystem influence fishery productivity.
5. Further engagement with government, business and researchers is needed to identify who might be best placed to operationalise ongoing natural capital accounts for commercial fisheries, given the feasibility and stakeholder interest demonstrated in FRDC Project 2017-175.

### *Scientific research*

6. To improve valuation of estuarine habitats using the stable isotope modelling approach, the use of additional tracers such as fatty acid profile or amino acids to separate sources more effectively is recommended.
7. To improve understanding of the drivers of contribution to diet of various species of commercial interest, further work combining stable isotope information from a broad suite of estuaries is recommended.
8. To improve understanding of the relationship between the commercial species of interest and the ecosystem, further studies are recommended to:
    a. determine the trophic link between estuarine habitat productivity and commercial fisheries, with a particular focus on larval and planktonic organisms that are likely to feed on primary productivity
    b. examine the direct flow-on effects of habitat rehabilitation to fishes of commercial or recreational interest.

## Keywords

*Metapenaeus macleayi*, conceptual modelling, natural capital accounts, Wallis Lake, commercial fisheries, estuarine habitats, saltmarsh, seagrass, mangrove

# Introduction

Primary industries rely on natural capital – the stock of renewable and non-renewable natural resources that combine to yield a flow of goods and services, which in turn provide benefits to an enterprise or society. Many businesses are showing strong interest in better accounting for the natural capital they manage, but to date, mechanisms to quantify the importance of these relationships have not been widely adopted by industry. Natural capital accounting provides a rigorous and repeatable method to directly link the goods and services produced by primary enterprises to the flow of environmental goods and services from natural capital.

The broader project *Lifting farm gate profits: the role of natural capital accounts* sought to determine whether natural capital accounting could support decision making and drive better productivity of primary industries, which depend on natural capital. The broader project was contracted through Forest and Wood Products Australia and was funded by the Rural Research and Development for Profit program (RRD4P), with $100,000 funding provided by the FRDC.

The broader project tested the application of natural capital accounting in three primary industries: cotton, fisheries and forestry. The FRDC Project 2017-175 contributed to the fisheries case study by:

- compiling data for experimental natural capital accounts
- identifying, interviewing and engaging stakeholders
- providing input and feedback on results and outputs from the broader project.

The FRDC Project 2017-175 built directly upon the FRDC 2013-006 project, which developed a novel approach to defining broad-scale linkages between fisheries and the natural assets that support them. Using stable isotopes to trace trophic flows throughout estuarine ecosystems, it was shown that a substantial proportion of the biomass of exploited estuarine species were supported by saltmarsh productivity in certain estuaries. Preliminary application of this approach led to the first estimates of the economic values of fisheries productivity derived from Australian saltmarsh and mangrove habitats, with values as high as $25,000 per hectare per year. This provided the platform to tackle challenges associated with applying natural capital accounting at an enterprise level for fisheries.

This project used the methods and data developed in the FRDC 2013-006 project, further refining the approach and testing potential indicators for inclusion in experimental natural capital accounts for fisheries. This should allow other estuarine fisheries across Australia to use this approach and create accounts for their fisheries to highlight value of estuarine assets.

# Objectives

The objectives of the FRDC Project 2017-175 were to:

1. link the profitability of prawn fisheries in NSW to the ecosystem services provided by natural assets, including
    a. **interviewing stakeholders** to assess understanding of ecosystem services and natural capital accounts
    b. building a stakeholder-driven **conceptual model** of the Wallis Lake environment that includes all the pressures that may affect or bring value to the prawn fishery
    c. develop a **biophysical model** that identifies the contribution of estuarine habitats in Wallis Lake to the diets of school prawn caught in the lake by commercial fisheries
2. identify and engage stakeholders related to prawn fisheries in NSW
3. increase stakeholders' awareness of and skills in natural capital accounting

# Method

Methods relating to each objective are summarised here. Cross-references are provided to the project outputs with more detail.

## Objective 1. Link the profitability of prawn fisheries in NSW to the ecosystem services provided by natural assets

### *Stakeholder interviews*

Stakeholder groups with an interest in wild-harvest fisheries in NSW were interviewed as described in the method for objective 2.

Additional details are provided in van Putten et al. (in review) and Chapter 3 of Schmidt et al. (2020).

### *Conceptual modelling*

We designed a conceptual model of the Wallis Lake prawn fishery and the ecosystem it was associated with. All stocks of assets and flows − as well as the interlinked flows to, within and from the combined ecosystem and enterprise system − were systematically identified and illustrated. These conceptual models were developed based on the stakeholder interviews and the biophysical expertise of the authors, supported by a literature review to identify evidence for the components and their linkages within the system.

The conceptual models were subsequently tested with stakeholders via two workshops with the Wallis Lake Estuary Management Committee and revised to reflect local understanding of the systems. This involved the inclusion or exclusion of aspects identified as crucial by stakeholders (for example, tourism) and reorganisation of pathways to include these. Natural capital accounting boundaries were then defined, based on the spatial characteristics of the system; flows to and from surrounding systems; and stakeholder needs for reporting.

Additional details are provided in Chapter 4 of Schmidt et al. (2020).

### *Biophysical modelling*

We obtained samples of all primary producers found in various sites within Wallis Lake to capture the variation in stable isotope values (Figure 1). These included mangroves, riparian vegetation, saltmarsh species (succulents and grasses), seagrasses, particulate organic matter, and fine benthic organic matter. We targeted five species of commercial interest in Wallis Lake, which were chosen according to their total landings value for the estuary: blue swimmer crab, sea mullet, dusky flathead, yellowfin bream, and school prawn. These were purchased directly from the Forster Fishery Co-Operative to accurately represent the organisms targeted by fishers. All samples were frozen until processing at the University of Newcastle.

All samples were thawed prior to processing. Primary producer samples were rinsed with de-ionised water. For commercial species of fish and crustaceans, approximately 1 g of muscle tissue was extracted. Samples were dried at 60 °C for 48 hours and ground to a fine powder using a Retsch MM200 ball mill. Approximately 9 mg of powdered sample was then placed in a glass tube and sent to Griffith University, QLD for stable carbon, nitrogen and sulfur isotope analysis.

To reduce uncertainty in the stable isotope mixing model, sources were grouped if their values overlapped. This was confirmed mathematically using ANOVAs, and sources that were significantly different to each other across either of the isotope tracers were kept distinct. The contribution of these grouped sources to the diets of commercially important species was then determined using a Bayesian stable isotope mixing model.

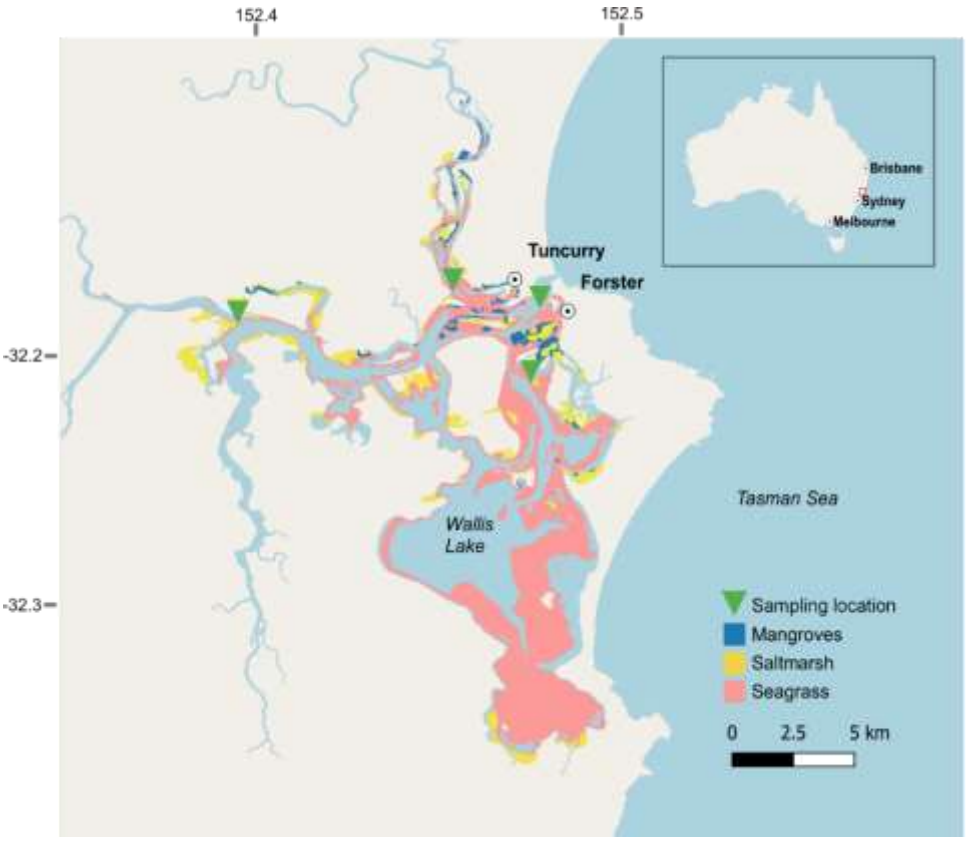


**Figure 1: Habitat sampling locations within Wallis Lake estuary. Map also displays estuarine habitats within the estuary identified from aerial imagery.**

The outputs from the initial model were then combined using known habitat extent and historical catch records of the targeted commercial species in Wallis Lake. Using a Monte Carlo Markov Chain approach that accounts for uncertainty, we then assessed the likely value of estuarine habitats based on the value of the landings and the modelled contribution of diet of estuarine habitats.

Additional details are provided in Raoult et al. (in review).

# Objective 2. Identify and engage stakeholders related to prawn fisheries in NSW

### *Stakeholder interviews*

A total of 36 interviews were conducted to determine how stakeholder groups with an interest in wild-harvest fisheries in NSW understand (and/or use) natural capital accounting – specifically, the commercial prawn-fishing industry in Wallis Lake estuary. Interviews were targeted to ascertain interviewees' level of knowledge of natural capital accounting and understanding of the ecosystem services the prawn-fishing industry relies upon.

Potential stakeholders and interviewees were identified through discussions with the local fishery and natural resource management community, as well as through recommendations from interviewees. This engagement was initiated via a field visit to Wallis Lake which included meetings with relevant officers from NSW Local Land Services (July 2018), who identified the Wallis Lake Estuary Management Committee as a key group of diverse stakeholders to meet with.

Stakeholders were categorised into three classes: industry, government and community. Within these three classes, 12 stakeholder groups relevant to the prawn-fishing industry were identified. Questions were designed to allow for quantitative analysis of:

- the value propositions (objectives) for natural capital accounting

- potential uses of natural capital accounts
- information gathered by each stakeholder (and/or their organisation)
- how that information is communicated.

Additional details are provided in van Putten et al. (in review) and Chapter 3 of Schmidt et al. (2020).

## Objective 3. Increase stakeholders' awareness of and skills in natural capital accounting

A collaborative extension model was employed where the project team interviewed stakeholders (see method for objective 2); assessed stakeholders' natural capital accounting objectives; and developed tools that facilitate adoption of natural capital accounts within existing reporting frameworks.

Subsequent to the interviews, we held two workshops with the Wallis Lake Estuary Management Committee (on 28 February 2019 and 29 May 2019) to:

- present conceptual model, gain feedback, and revise in response
- test which impacts and dependencies to prioritise for reporting via natural capital accounts
- present risks to prawn productivity, followed by adjustment of results based on their feedback.

This committee was renamed the Wallis and Smiths Coast and Estuaries Committee, and on 25 November 2020 a further meeting was held with them via Zoom (due to COVID-19 travel restrictions) to:

- present and test these proposed natural accounts
- to share the final technical reports and the public-audience summary in advance of publication.

Additional details are provided in Schmidt et al. (2020).

# Results, discussion and conclusions

Results, discussion and conclusions relating to each objective are summarised here. Cross-references are provided to the project outputs with more detail.

## Objective 1. Link the profitability of prawn fisheries in NSW to the ecosystem services provided by natural assets

### *Stakeholder interviews*

Chapter 3 of Schmidt et al. (2020) reports the results of stakeholder engagement aimed at better understanding the value proposition for natural capital accounting in the prawn-fishing industry. These interviews provided critical information on market and non-market drivers, which was used to inform the conceptual model of the system and to design natural capital accounts that meet the highest priority stakeholder needs.

A wide range of 'value propositions' for the use of natural capital accounting in the wild-caught fishing industry were identified by stakeholders (Figure 2), and these were explored across stakeholder groups.

Additional details are provided in van Putten et al. (in review) and Chapter 3 of Schmidt et al. (2020).

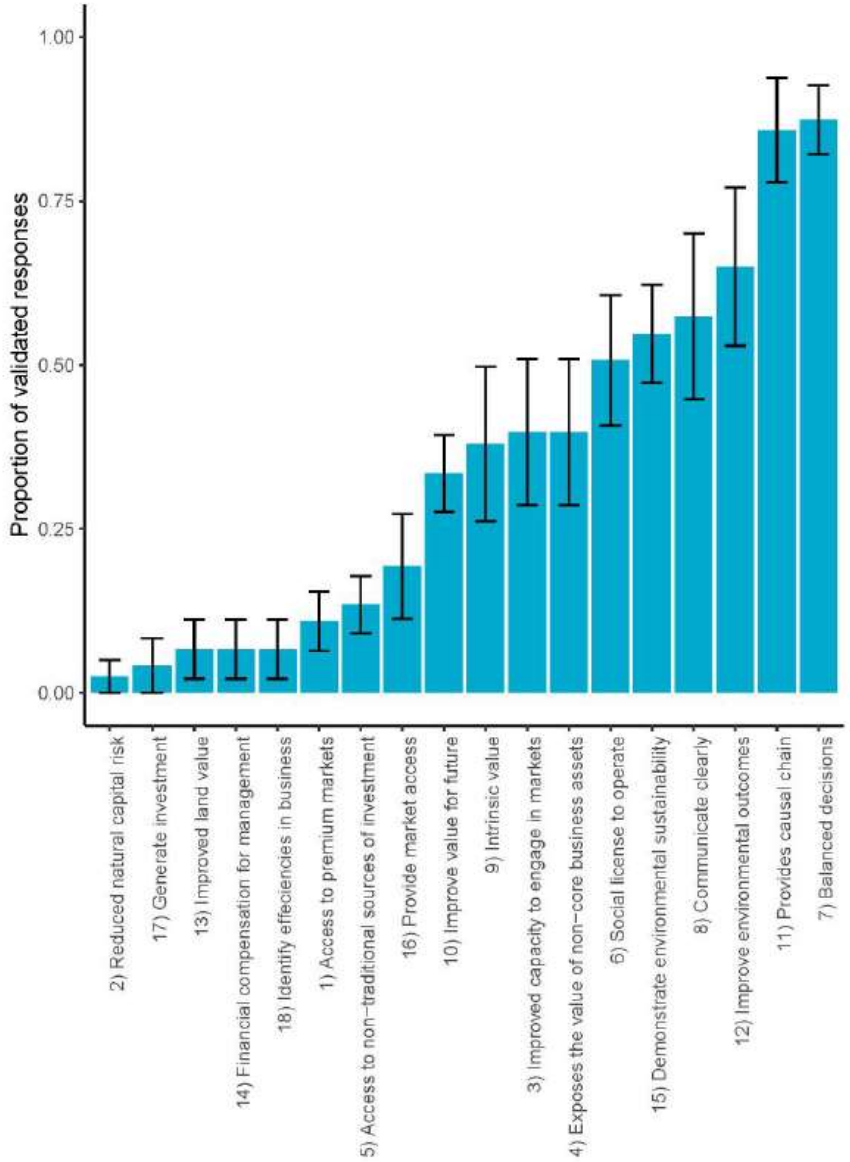


**Figure 2: Proportion of responses per number of interviewees across all stakeholder groups validating (but not debunking) the value propositions for natural capital accounting (mean ± standard error).**

### *Conceptual modelling*

Chapter 4 of Schmidt et al. (2020) presents a conceptual model of the prawn-fishing industry's interaction with natural capital, which is necessary to track and manage natural capital via accounts. The conceptual model characterises the stocks and flows of natural capital for the prawn-producing ecosystem and prawn-fishing enterprises in Wallis Lake estuary (Figure 3).

The ecosystem includes stocks of assets such as estuarine waters suitable for prawns, prawn-producing habitat, biodiversity, ecological interactions, prawn-producing capacity and renewable prawn population.

The conceptual model included numerous changes after suggestions from the stakeholders. These included the addition of blue carbon as an asset, as well as algal habitats. We also separated agricultural runoff from other pathways due to its overarching influence. Tourism was also related the prawn-fishing industry due to the close link between these two activities.

Additional details are provided in Schmidt et al. (2020).

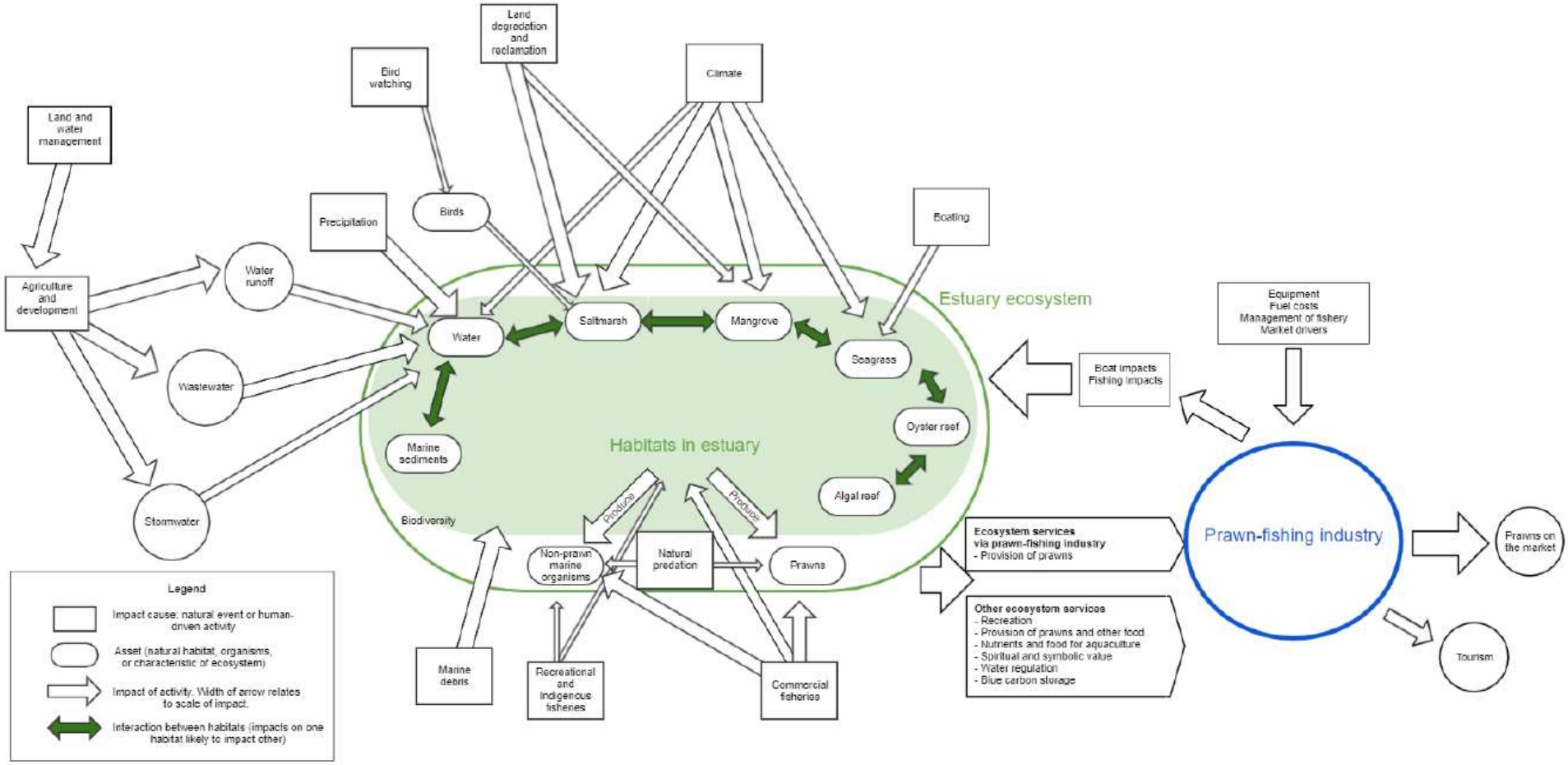


**Figure 3: Conceptual model for the Wallis Lake estuary, illustrating flows between impact causes (activities or events), assets (natural capital), the estuarine ecosystem (large green oval) and the prawn-fishing industry (blue oval).**

### *Biophysical modelling*

An isotopic group comprising mangroves and other sources was the most important source for both *Portunus armatus* (blue swimmer crab; contribution of 0.44 ±0.06; mean ±SD) and *Metapenaeus macleayai* (school prawn; contribution of 0.69 ±0.04), followed by seagrasses (contributions of 0.39 ±0.11 and 0.12 ±0.05, respectively; Figure 4). The density distributions of the estimated contributions for crustaceans were usually constrained for the mangrove group and more broadly distributed for seagrasses and *S. virginicus*, indicating consistent results for the mangrove group and higher individual variability for seagrasses and *S. virginicus*. Fine benthic organic matter (FBOM) had very low, constrained contributions (mean <0.1 for both crustaceans) suggesting its contribution to the diets of crustaceans was negligible.

The valuation of habitats across five species commercially fished in Wallis Lake showed that the relative value of the three estuarine habitats varied considerably among species. Blue swimmer crabs (*Portunus armatus*) had the highest associated value for each estuarine habitat, with medians of over AUD $50,000 $yr^{-1}$ per habitat (all values expressed as 2018 values), driven by the volume of harvest combined with the species per-kg value. For four of the five consumer species, saltmarshes had the highest value, while mangroves had the lowest value. The exception being blue swimmer crabs, where seagrasses were of the highest value, followed by saltmarshes and then mangroves (Figure 5).

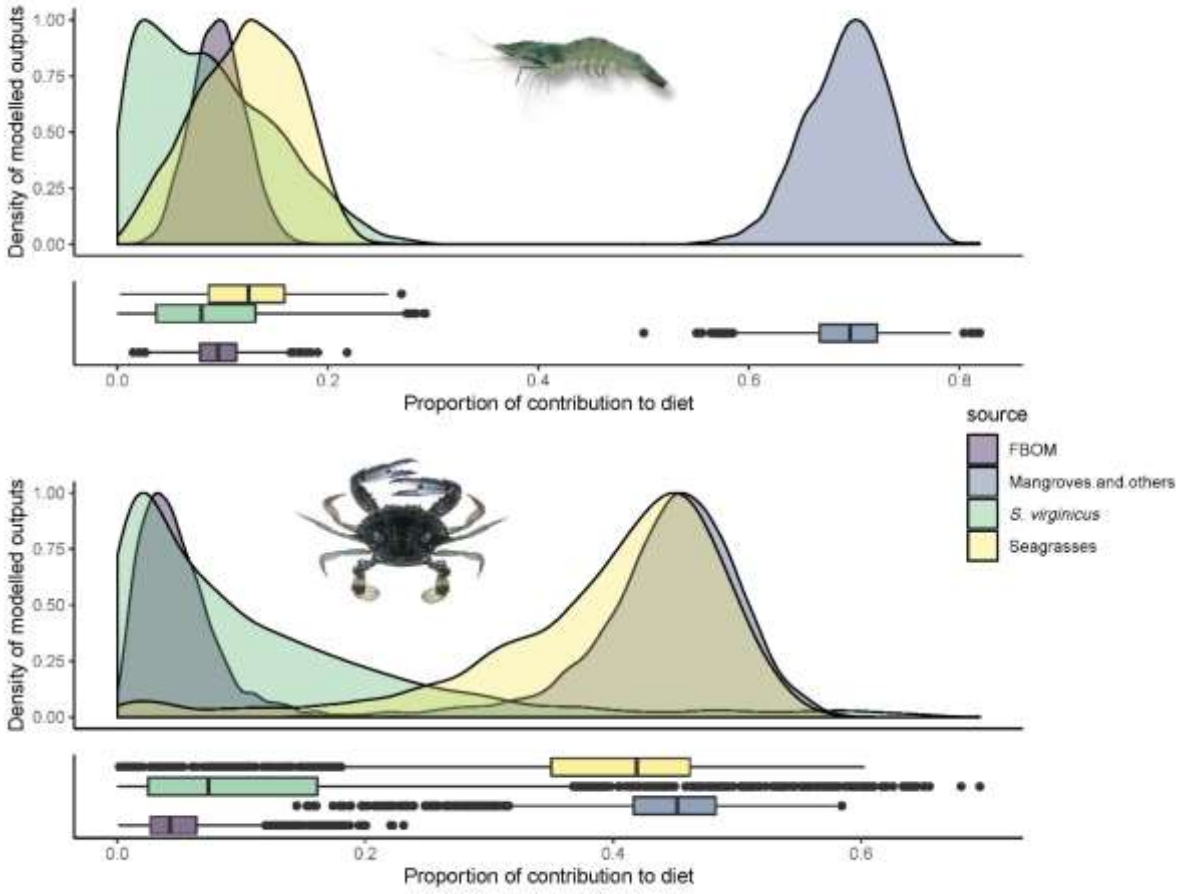


**Figure 4: Posterior density distributions of proportions of contributions to the diets of crustaceans (*Metapenaeus macleayi* top, *Portunus armatus* bottom) of estuarine habitats, as modelled by Bayesian stable isotope mixing models. Each density distribution has an associated boxplot directly below to help with the interpretation of the data.**

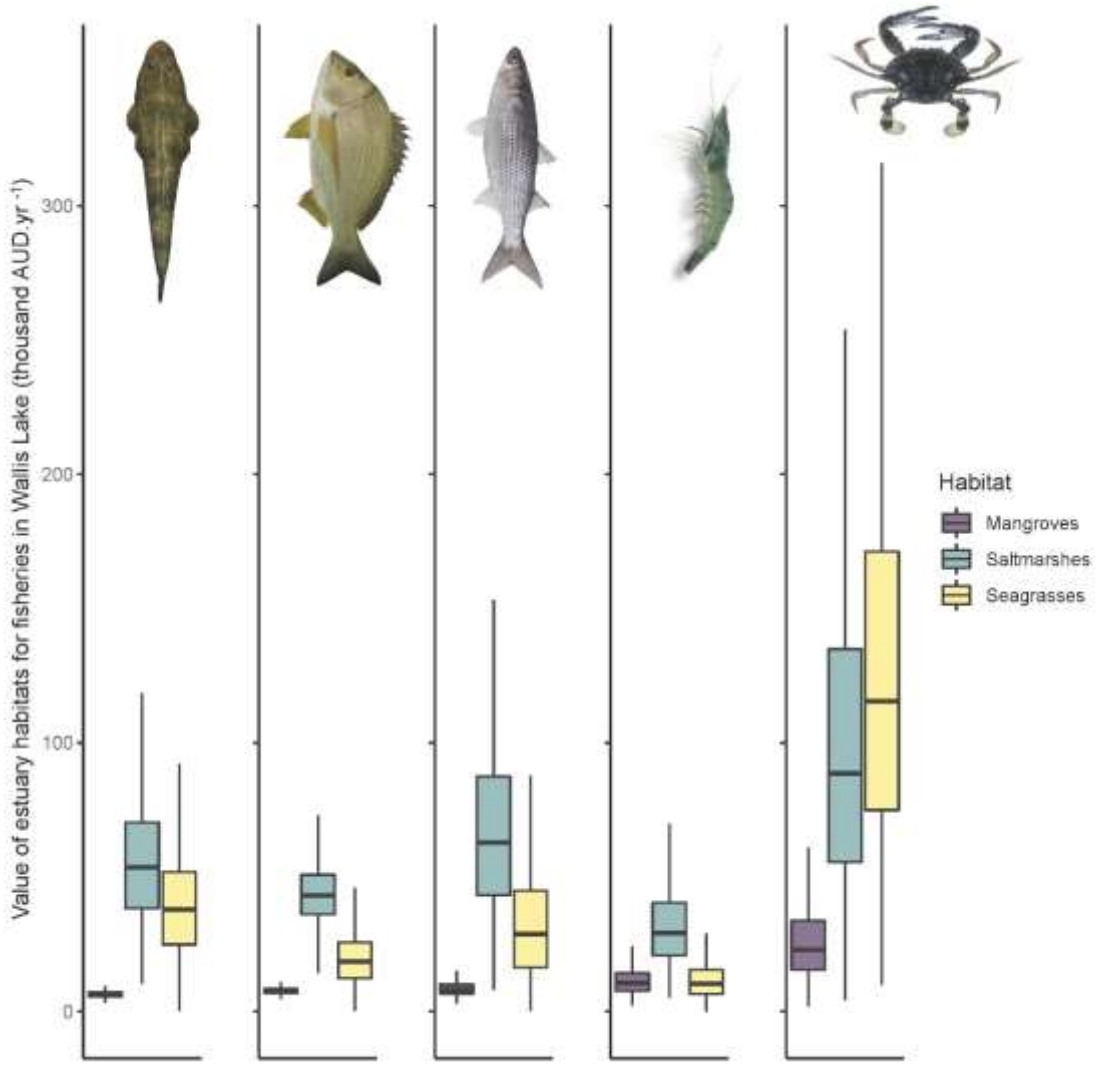


**Figure 5: Boxplots of modelled value of estuarine habitats found in Wallis Lake to commercial fisheries in the area calculated from Bayesian stable isotope mixing models.**

Using the current areal extent of each habitat type in the Wallis Lake estuary, the per-hectare value of saltmarshes was also highest (AUD $621 ±191 $ha^{-1}yr^{-1}$), followed by mangroves (AUD $227 ±66 $ha^{-1}yr^{-1}$) and seagrasses with the lowest value (AUD $63 ± 29 $ha^{-1}yr^{-1}$, median ±SD). These patterns were mirrored in the total economic value of habitats (extrapolating the broader value of product to the economy), also known as 'Total Value of Product' (TVP), which was highest for saltmarshes (AUD $1.7 million $yr^{-1}$). Overall, the cummulative TVP for fisheries production derived from the habitats and species described here was ~AUD $3.4 million $yr^{-1}$ (Figure 6).

We measured higher estimated economic value of saltmarsh and seagrass habitats relative to mangroves for the five commercially fished species examined. Three consumer species had the highest dietary contribution from mangroves and associated sources, and the other two had the highest dietary contribution from *S. virginicus*. Fine benthic organic matter showed little to no dietary contribution for the five consumer species, whereas seagrasses often had contributions greater than 20%, ranging to over 40% for *P. armatus*. While these analyses are partial valuations, our results highlight that the economic value of estuarine habitats as fisheries may be constrained by their natural resource base, a pattern that is likely to be present across other estuarine systems. For example, very abundant habitats like seagrasses appeared to lead to lower per-hectare value estimate for this resource. Conversely mangroves, despite having a lower contribution to the diets of all five consumer species, had a per-hectare value higher than that of seagrasses, based on their low

habitat extent in the estuary. This raises some important considerations for prioritising repair and rehabilitation.

Quantifying explicit linkages between ecosystem services provided by habitats comprised of primary producers (mangroves, saltmarshes and seagrasses) to beneficiaries (the fishing enterprises and the customers who buy seafood) is an important step in improving the knowledge base for the management of our natural assets. Demonstrating the value of intact intertidal and subtidal habitats through assessment of their contribution to the diets of exploited species highlights that integrated catchment management is key to the long-term sustainability of our fishing industry.

While our study addresses only part of this value, it nonetheless demonstrates the importance of multiple habitats within a healthy ecosystem in the provision of seafood. This highlights the need for ongoing conservation of coastal ecosystems, as well as the potential value that may be achieved through targeted habitat repair, which could lead to increases in fishery productivity in the future.

A more detailed discussion of these results is available in Raoult et al. (in review).

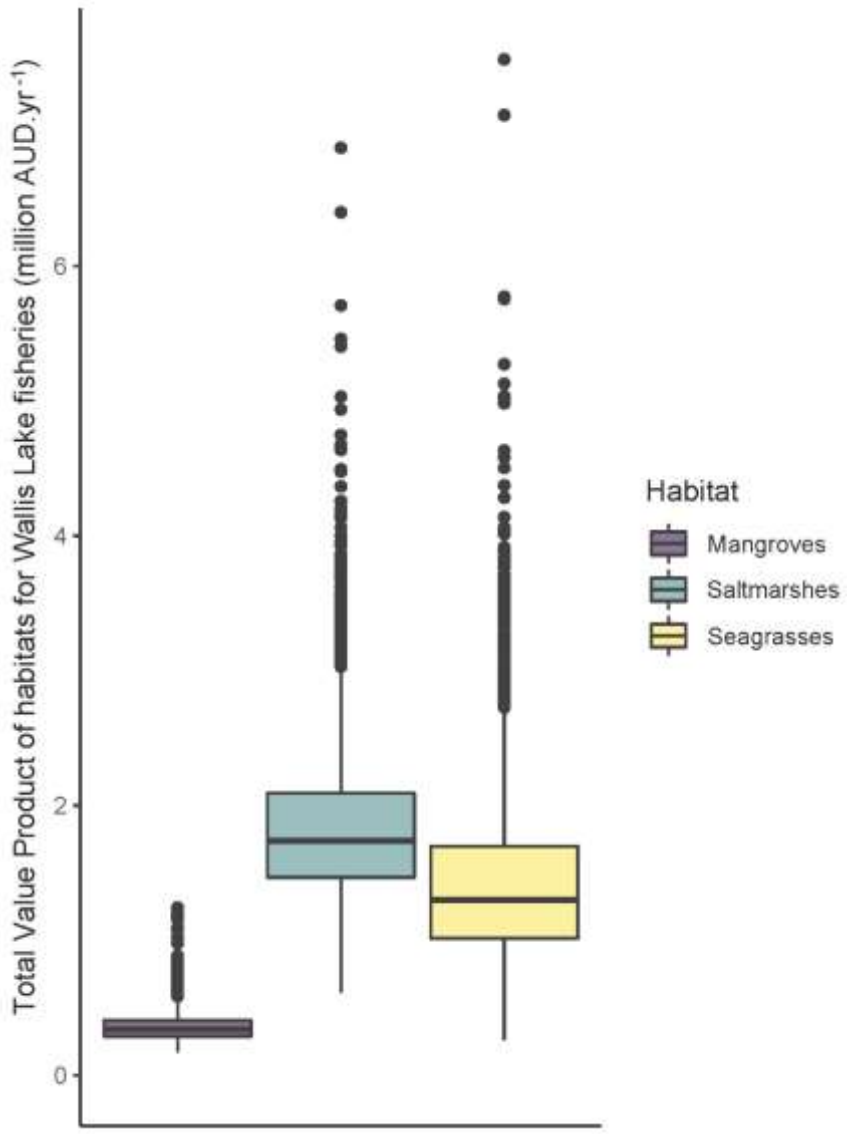


**Figure 6: Boxplots of distribution of modelled cumulative value of estuarine habitats found in Wallis Lake to commercial fisheries and the broader economy in the area (Total Value of Product), calculated from Bayesian stable isotope mixing models.**

## Objective 2. Identify and engage stakeholders related to prawn fisheries in NSW

As part of the interviews held at the beginning of the project a broad cross-section of stakeholders was identified and interviewed. We interviewed only a small number of key industry participants due to concerns around 'consultation fatigue'. Those selected were considered key figures in the area who could speak on behalf of the industry. We were unfortunately unable to secure interviews with local Indigenous representatives or certification agencies.

Chapter 3 of Schmidt et al. (2020) analyses the 36 interviews we were able to conduct for a diverse range of stakeholders. These interviews provided critical information on market and non-market drivers, which was used to inform the conceptual model of the system. The interviews were used to design natural capital accounts that meet the highest priority stakeholder needs.

While the specific information needs of stakeholder groups may differ, all stakeholders confirm there is consistent need for verifiable understanding of ecosystem state and condition. The process of generating natural capital accounts relies on stakeholder testing to validate the usefulness of the accounts, and this report confirms the great value in undertaking detailed and iterative engagements across stakeholder groups, which help build understanding of the outcomes being sought. The strong interrelation between fishery enterprises and the natural assets on which they rely, as well as the broader community concern to minimise environmental damage to estuaries, provides a compelling rationale for investment in natural capital accounts that meet multiple objectives.

Additional details are provided in van Putten et al. (in review) and Chapter 3 of Schmidt et al. (2020).

## Objective 3. Increase stakeholders' awareness of and skills in natural capital accounting

Stakeholders prioritised the following major activities and events for natural capital accounting:

- freshwater pulses
- agriculture
- commercial fisheries.

These priorities guided the selection of the following accounts, which were compiled by the broader project:

- precipitation in the catchment
- freshwater pulses in the catchment
- land use in the catchment
- terrestrial and riparian vegetation in the catchment
- aquatic prawn habitat
- water quality in the prawn habitat
- landed prawn biomass in the fishable area.

For example, Table 1 shows an account of landed prawn biomass measured in physical terms, disaggregated to contributions from the seagrass, mangrove and saltmarsh aquatic habitats. The primary biophysical datasets are the productivity of the fisheries measured in tonnes per year, as well as new data generated in this FRDC project on the contribution of each aquatic habitat to the amount and monetary value of the prawn catch.

The natural capital accounts produced here are a 'first cut' based on an extensive literature search of key causal pathways impacting and influencing prawn production in estuarine environments in Australia, and are designed to help explain those natural and anthropogenic processes in a simple format. It brings together for the first time key information on whole-of-catchment estuarine characteristics that impact on prawn productivity.

At the final presentation of these natural capital accounts to the Wallis and Smiths Coast and Estuaries Committee on 25 November 2020, stakeholders gave positive feedback, describing it as an 'excellent presentation' of interesting information that would be useful in cost-benefit analyses, and also to aid planning to mitigate climate change. Committee members requested additional analysis of other species (whiting, mud crab) and emphasised the importance of seagrass for the greasyback prawn.

This process now requires interpretation and validation through further engagement with stakeholders, in particular the fishing industry, to help refine as well as to bring forward new lines of evidence to inform the concepts presented here.

A more detailed discussion of these results is available in Schmidt et al. (2020) and Ware et al. (2020).

**Table 1 Ecosystem service account: landed biomass of School Prawn in the fishable area, disaggregated by the contribution of estuarine habitats, in 1971/1972, 1985/1986 and 2017/2018. The contribution of each habitat is expressed monetarily, with values derived using a model similar to Taylor and Creighton (2018). Note that per-species data on School Prawns were not available before 1985. As a result, the value of habitats for 1971/1972 was calculated from the landings and value of prawns in the 2017/2018 dataset. (see Ware et al. (2020) for context and more details)**

| YEAR | SALTMARSH | | MANGROVE | | SEAGRASS | | TOTAL (ALL HABITATS IN WALLIS LAKE) | |
|---|---|---|---|---|---|---|---|---|
| | Areal extent of saltmarsh habitat (ha) | Value of contribution of saltmarsh to prawn diet ($/ha) (mean ± SD) | Areal extent of mangrove habitat (ha) | Value of contribution of mangrove to prawn diet ($/ha), (mean ± SD) | Areal extent of seagrass habitat (ha) | Value of contribution of seagrass to prawn diet ($/ha) (mean ± SD) | Landings (tonnes), mean ± SD | Value ($1000s), mean ± SD |
| **1971/1972** | 617 | $52.79 ± 26.84 | 117 | $97.90 ± 46.40 | 2790 | $4.29 ± 2.76 | 20.73 ± 7.06 | $56.00 ± 29.69 |
| **1985/1986** | 400 | $81.33 ± 41.34 | 79 | $145.74 ± 69.07 | 3079 | $3.89 ± 2.50 | 28.55 ± 11.53 | $91.00 ± 69.01 |
| **2017/2018** | 472 | $69.01 ± 35.08 | 251 | $45.64 ± 21.63 | 3480 | $3.44 ± 2.21 | 20.73 ± 7.06 | $56.00 ± 29.69 |

# Implications for future use of natural capital accounts in fisheries

While the project ably demonstrates the usefulness of producing natural capital accounts for primary industries, and in particular, commercial fisheries, it also identified a number of key limitations that currently would limit easy uptake of natural capital accounts by fishers. Stakeholder engagement identified that the approach was not only valuable for fisheries, but also of great interest to local stakeholders in both government and the public. Stakeholders agreed the approach would be useful for supporting targeted rehabilitation within estuarine systems given the inextricable link between habitats, productivity and profitability. Further engagement with local Indigenous groups and other local communities would be critical to include a broader range of values of the estuaries.

The study confirmed that conceptualising, defining and quantifying the biophysical aspects of a business's interactions with natural capital provides the necessary basis for businesses and managers to assess the risks and opportunities associated with their impacts and dependencies. These potentially include operational, legal, regulatory, reputational, financial and social risks as well as additional business opportunities.

Through identifying key drivers that affect the habitat condition for prawns, the study has demonstrated it is possible to simplify the critical information needed by estuary managers, prawn fishers and the general community to inform future decision-making. This process has the capacity to be translated to other any estuarine or coastal commercial fishery in Australia: engage with stakeholders, develop the conceptual and biophysical models, and produce the natural capital accounts.

The issue of adequate data at the appropriate resolution, including availability of regularly updated information, is an important consideration for stakeholders considering implementing and operationalising these natural capital accounts. This remains a key limitation to widespread adoption of natural capital accounts to small-scale fisheries. It can be overcome but will require additional investment.

The issue of who might be best placed to operationalise ongoing natural capital accounts also needs to be addressed. Our stakeholder engagement revealed that small-scale fishery enterprises are unlikely to develop natural capital accounts by themselves. This suggests that a different organisation is better placed to develop the accounts, potentially a local or state government; or consultants commissioned jointly by several industries that share the resources of the estuary; or a research agency or peak body tasked with supporting the viability of local industries.

At an estuary-wide scale, compilation of natural capital accounts can improve knowledge of ecosystem processes and function as well as identify where to target on-ground actions to repair both habitat and fishery productivity and profitability. The linking of ecosystem services to profitability has the potential for improving long term sustainability of industries at a much broader scale as it is applied across the primary industries of fisheries, forestry and agriculture.

# Recommendations

## Natural capital accounting

Seven natural capital accounts were proposed for the Wallis Lake prawn fishery, on the basis of priorities identified by stakeholder needs, an analysis of impacts on natural capital, and the availability and quality of data. **The study showed that to be of greatest use there is need to broaden the number of accounts prepared to cover all uses of the estuary, not just those primarily related to the fishery. Additional accounts would be required to cover all ecosystem services that occur in the estuary (for example, carbon sequestration, recreational fishing, other fisheries not considered here, and offshore fisheries that may derive productivity from the estuary).**

**To extend the usefulness of the approach it is recommended to expand the conceptual model and natural capital accounts to consider all interdependencies that occur within and immediately outside the estuary system – not just those related to the fishery (e.g. climate change, development due to growing population).**

**To improve the usefulness of the environmental-economic valuation of the fishery, future studies would benefit from development of new methods to value non-dietary aspects of the habitat, such as nursery use, shelter from predation, and reproduction.**

More finely resolved data through time would enhance our ability to predict how changes in the landscape and ecosystem may influence prawn productivity. For example, it is expected that the timing, number and intensity of freshwater pulses should relate to prawn catches; however it would require at least monthly records of prawn catch to identify the overall value of freshwater pulses on prawn catch aggregated annually. Similarly, the temporal resolution of data on areal extent of habitats was sparse, meaning identifying trends in account value was difficult. More consistent records of these key variables should allow better characterisation of account values. **To provide management-relevant accounts, it would be necessary to collect more finely resolved temporal data (e.g. on freshwater pulses and changes to habitats), as this would enhance our ability to predict how changes in the landscape and ecosystem influence fishery productivity.**

**Further engagement with government, business and researchers is needed to identify who might be best placed to operationalise ongoing natural capital accounts for commercial fisheries, given the feasibility and stakeholder interest demonstrated in FRDC Project 2017-175.**

## Scientific research

A key to improving the usefulness of the research undertaken in this project will be to improve the certainty of the valuation based on the isotopic signatures. The study was constrained by separating source stable isotope signatures using just two isotope tracers (nitrogen was considered influenced by anthropogenic activities and had to be excluded). Valuing habitats was difficult when key habitats have indistinct or overlapping stable isotope values (for example, saltmarsh succulents and riparian vegetation). The approach we used to solve this issue was parsimonious but could potentially falsely attribute some or most of the contribution to one or the other habitat depending on the number of sources present. **To improve valuation of estuarine habitats using the stable isotope modelling approach, the use of additional tracers such as fatty acid profile or amino acids to separate sources more effectively is recommended.**

The approach used could be significantly improved through a greater understanding of the biophysical link between species of interest and estuarine habitats through increased on-ground assessments of these trophic linkages. **To improve understanding of the drivers of contribution to diet of various species of commercial interest, further work combining stable isotope information from a broad suite of estuaries is recommended.** This would allow a better understanding of which

estuarine habitats are key for a given species of commercial interest, and how coverage of estuarine habitat affects contribution to diet and therefore productivity. Further work is currently underway to broaden our research base by combining our results from this and other studies across NSW with those undertaken in Queensland (Raoult et al., in prep.).

There is now mounting biophysical evidence for the value of estuarine habitats for fisheries. However, this evidence is usually collected *a posteriori* without a direct examination of the link that may occur between habitats and fishes. These patterns can result in uncertainty for managers assessing whether it will be cost-effective to rehabilitate habitats. **To improve understanding of the relationship between the commercial species of interest and the ecosystem, further studies are recommended to:**

- **determine the trophic link between estuarine habitat productivity and commercial fisheries, with a particular focus on larval and planktonic organisms that are likely to feed on primary productivity**
- **examine the direct flow-on effects of habitat rehabilitation to fishes of commercial or recreational interest.**

# Extension and adoption

Objective 2 of this project was to *Identify and engage stakeholders related to prawn fishing in NSW.* As such, stakeholder engagement and extension were a key focus of the broader project.

Extension activities throughout the project were focused on closely engaging with industry when conceptualising and designing of industry-relevant natural capital accounts, as well as producing reports, papers and stakeholder information packages.

### *Stakeholder mapping and consultation to ensure that natural capital accounts meet a range of stakeholder requirements*

After the stakeholder interviews, we designed a conceptual model of the Wallis Lake prawn fishery and the ecosystem it was associated with. Initially we produced a simpler conceptual model designed to be further refined after group stakeholder engagement. All stocks of assets and flows were then systematically identified and combined in a more complex conceptual model.

The conceptual models were subsequently tested with stakeholders via two workshops with the Wallis Lake Estuary Management Committee and revised to reflect local understanding of the systems. This involved the inclusion or exclusion of aspects identified as crucial by stakeholders (for example, tourism) and reorganisation of pathways to include these. Natural capital accounting boundaries were then defined, based on the spatial characteristics of the system; flows to and from surrounding systems; and stakeholder needs for reporting.

We identified seven primary accounts that could be directly linked to the Wallis Lake prawn fishery. These included precipitation, freshwater pulses, land use, terrestrial/riparian vegetation, water quality, prawn habitat extent, and landed prawn biomass within this fishable area. Across all stakeholder groups, stakeholders identified 'balancing decisions' and 'providing evidence of causal chains' most often as valid reasons for using natural capital accounts. In general, more interviewees answered favourably about the potential for natural capital accounting to be useful, identifying more drivers than barriers to adopting this process.

### *Development of information packet for stakeholders, including plain English summaries to promote the understanding of natural assets underpinning productive fisheries and to explain the technical results to non-technical audiences.*

*Natural capital accounting for the prawn-fishing industry* (Attachment 1) is a factsheet providing a plain English summary of FRDC Project 2017-175. This was distributed to the Wallis and Smiths Coasts and Estuary Committee.

A second factsheet was developed that provides a plain English summary of the broader RRD4P project (Attachment 2).

### *Presentation of results in conferences and fora, e.g. those organised by the natural capital coalition*

Key results of the project were presented via the following fora:

- Two presentations to the Wallis Lake Estuary Management committee (28 February 2019 and 29 May 2019) and one presentation to the Wallis and Smiths Coasts and Estuary Management Committee (25 November 2020)
- Four presentations to the Steering Committee for the RR4DP project *Lifting farm gate profits: the role of natural capital accounts* (14 April 2018, 26 November 2018, 8 August 2019 and May 2020)
- Conference presentations

- Ian Cresswell gave an oral presentation entitled 'Valuing mangroves and saltmarshes to improve economic, social and environmental outcomes' to the Coast to Coast National Conference, Hobart (2018)
- Ian Cresswell gave an oral presentation entitled 'The role of saltmarshes to improve economic, social and environmental outcomes in a prawn fishery' to the Australian Mangrove and Saltmarsh Network Annual Conference (2019)
- Vincent Raoult gave an oral presentation to the World Fisheries Congress, on the biological model underpinning this work (October 2020)

Testing in the international domain occurred via following activities:

- Conceptual modelling report reviewed by author of Natural Capital Protocol
- This led to the prawn fishery case study being given as an example in the draft report *Natural Capital Approaches for Biodiversity* led by the Natural Capital Coalition, as well as a presentation by Anthony O'Grady (Project Leader of the RR4DP project) on 4 December 2021
- Engagement with national and international environmental-economic accounting fora and workshops, including SEEA-EEA revisions and the London Group on Environmental Accounting
- Engagement at international Natural Capital Week in 2018 (Paris)

### *Journal publications*

Two journal publications have been written and are currently in review, and a third journal publication is in preparation.(Attachments 1, 2 and 3)

### *Project coverage*

At the project's inception, a media release was developed and provided to a number of outlets and posted to social media to engage and inform the wider community. Most recently, the project was covered in a September issue of the FRDC magazine in an article entitled Prawn fishery counts its natural capital.

# Project materials developed

The outputs specified in the project agreement are:

1. journal publication on the Wallis Lake habitat valuation
2. journal publication for a state-wide model/framework
3. sections of report on fishery case study (published as part of the broader RRD4P project)
4. an information packet for stakeholders.

The datasets specified in the project agreement are:

1. physicochemistry of aquatic systems (temperature, conductivity, flow) collected from the mouth and lower estuary for Wallis Lake
2. a fishery-independent dataset of Eastern King Prawn and Eastern School Prawn for Wallis Lake including stable isotope ratios
3. natural estuarine assets associated with the life history of both Eastern King Prawn and Eastern School Prawns in Wallis Lake, covering extent and condition, including existing information on vegetation communities (saltmarshes and mangroves)
4. modelled links between fishery and habitat connectivity.

Below are listed the project materials delivered as outputs and datasets.

## Journal publications

Raoult V., Taylor D., Schmidt R., Cresswell I., Ware C., Gaston T. (in review) Valuing the contribution of estuarine habitats to commercial fisheries in a seagrass-dominated estuary. Submitted to *Estuaries and Coasts.*

- This is **output 1** as specified in project agreement.
- Currently in review.
- **Datasets 2 and 4** will be published with the journal article.

van Putten I.E., Pinkard E., O'Grady A., Schmidt R.K., Cresswell I., Raoult V., Taylor D. (in review) Stakeholder perspectives on the value proposition of enterprise-level natural capital accounting for three primary industries. Submitted to *Ecosystem Services.*

- This journal article was written as part of the broader RRD4P project, comparing and contrasting the results of these interviews across the three industries targeted in that project (cotton, fisheries and forestry).
- This was not specified as an output in the FRDC 2017-175 project agreement but the topic directly relates to objective 2: identify and engage stakeholders related to prawn fisheries in NSW
- Currently in review.

Raoult V., Taylor M.D., Connolly R., Schmidt, R.K., Ware C., Cresswell I.D., Gaston T.F. (in prep.) Linking estuarine habitat extent and fisheries productivity on a coastal scale: high inter-estuary variability suggests estuary-specific trophic pathways.

- This is **output 2** as specified in project agreement.
- In analysing the NSW data, it was determined that it is necessary to include more data in order to result in a scientifically credible broader model. Therefore we have initiated a collaboration with R Connolly to extend to include Queensland data.
- The analysis is underway, and the abstract has been written.
- Once draft paper is completed, we will submit to FRDC for review.

## Reports

Schmidt R.K., Raoult V., Cresswell I.D., Ware C., Taylor M.D., Mount R.E., Stewart S.B., O'Grady A.P., Pinkard E., Gaston T.F. (2020) Designing natural capital accounts for the prawn-fishing industry. A report to Forests and Wood Products Australia and Department of Agriculture, Water and the Environment from the *Lifting farm gate profits: the role of natural capital accounts* project (RnD4Profit-16-03-003). CSIRO, Australia. EP202165.

- This is **output 3** as specified in project agreement.
- The report presents the analysis and data developed in the FRDC and RRD4P projects.
- It has been accepted and approved by the Steering Committee of the RRD4P project.
- It was distributed to the Wallis and Smiths Coast and Estuary Management Committee in advance of a presentation on 25 November 2020.
- The report has been published on CSIRO's ePublish repository via the following URL: https://doi.org/10.25919/y5da-0919

Ware C., Stewart S.B., Cresswell I.D., Schmidt R.K., Raoult V., Taylor M.D., Mount R.E., Pinkard E.A., Gaston T.F., O'Grady A.P. (2020) Experimental natural capital accounts for the prawn-fishing industry in the Wallis Lake estuary. A report to Forests and Wood Products Australia and Department of Agriculture, Water and the Environment from the *Lifting farm gate profits: the role of natural capital accounts* project (RnD4Profit-16-03-003). CSIRO, Australia. EP202024.

- This is **output 3** as specified in project agreement.
- The collated **datasets 1 and 3** are presented in this report.
- The report presents the natural capital accounts developed in the FRDC and RRD4P projects.
- It has been accepted and approved by the Steering Committee RRD4P project.
- It was distributed to the Wallis and Smiths Coast and Estuary Management Committee in advance of a presentation on 25 November 2020.
- The report has been published on CSIRO's ePublish repository via the following URL: https://doi.org/10.25919/r9wg-1v84

## Information packet for stakeholders

The following products comprise **output 4** as specified in project agreement. In addition, an article titled Prawn fishery counts its natural capital was published in FISH magazine vol 28 2 in 2020.

### *Attachment 1*

Schmidt R.K., Raoult V., Cresswell I., Taylor M.D., Ware C., Gaston T.F. (2020) Natural capital accounting for the prawn-fishing industry. CSIRO Australia.

- This public-audience summary for the fisheries case study was distributed to the Wallis and Smiths Coast and Estuary Management Committee in advance of a presentation on 25 November 2020.
- This will be published on CSIRO's public webpage and a URL will be provided to FRDC so that they can cross-link from their webpage.

### *Attachment 2*

Pinkard, E.A., Schmidt R.K., O'Grady A. (2020) Natural capital accounting in Australia's primary industries. CSIRO Australia.

- This public-audience summary for the broader RRD4P project will be published on CSIRO's public webpage and a URL will be provided to FRDC so that they can cross-link from their webpage.

# Appendix 1: List of researchers and project staff

## FRDC Project 2017-175

CSIRO: Rebecca Schmidt, Chris Ware

University of Newcastle: Ian Cresswell, Troy Gaston, Vincent Raoult

NSW DPI: Matt Taylor

## Broader project: Lifting farm gate profits: the role of natural capital accounts project (RnD4Profit-16-03-003)

CSIRO: Richard Mount, Anthony O'Grady, Elizabeth Pinkard, Rebecca Schmidt, Stephen Stewart, Ingrid van Putten, Chris Ware

University of Newcastle: Ian Cresswell

# References

Raoult V, Taylor D, Schmidt RK, Cresswell I, Ware C and Gaston T (in review) Valuing the contribution of estuarine habitats to commercial fisheries in a seagrass-dominated estuary. Submitted to Estuaries and Coasts.

Raoult V, Taylor MD, Connolly R, Schmidt RK, Ware C, Cresswell ID and Gaston TF (in prep.) Linking estuarine habitat extent and fisheries productivity on a coastal scale: high inter-estuary variability suggests estuary-specific trophic pathways.

Schmidt RK, Raoult V, Cresswell ID, Ware C, Taylor MD, Mount RE, Stewart SB, O'Grady AP, Pinkard E and Gaston TF (2020) Designing natural capital accounts for the prawn-fishing industry. A report to Forests and Wood Products Australia and Department of Agriculture, Water and the Environment from the Lifting farm gate profits: the role of natural capital accounts project (RnD4Profit-16-03-003). CSIRO, Australia. EP202165.

van Putten IE, Pinkard E, O'Grady A, Schmidt RK, Cresswell I, Raoult V and Taylor M (in review) Stakeholder perspectives on the value proposition of enterprise-level natural capital accounting for three primary industries. Submitted to Ecosystem Services.

Ware C, Stewart SB, Cresswell ID, Schmidt RK, Raoult V, Taylor MD, Mount RE, Pinkard EA, Gaston TF and O'Grady AP (2020) Experimental natural capital accounts for the prawn-fishing industry in the Wallis Lake estuary. A report to Forests and Wood Products Australia and Department of Agriculture, Water and the Environment from the *Lifting farm gate profits: the role of natural capital accounts* project (RnD4Profit-16-03-003).