Department of Primary Industries NSW
Department of Regional NSW

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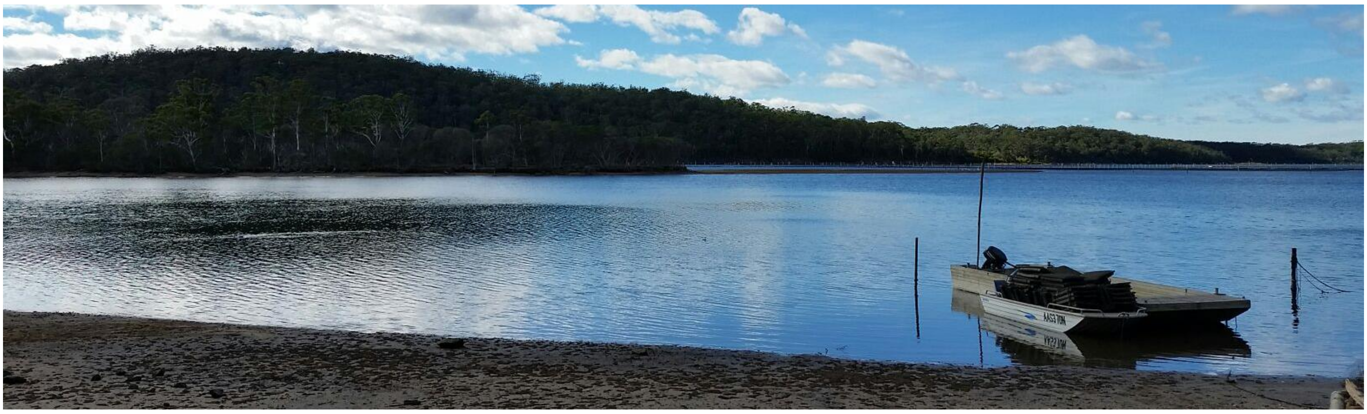
Drought & Above Average Rainfall Impacts on the Net Returns to NSW Oyster Production – Using Real-Time Sensors



Pambula Lake harvest area, Pambula River, NSW (image credit Dr. Penelope Ajani)

Executive Summary

The “open” or “closed” status of commercial oyster harvest areas is primarily modelled on rainfall data. Reliable salinity sensor data, as an indicator of how runoff from rainfall can impact estuaries, can enhance harvest area management plans through the provision of high frequency, real-time information. The use of salinity-based management for oyster harvesting, in comparison to a rainfall-based management system, aims to keep leases open longer to improve the returns to oyster production and to enhance food safety.

In this Cost Benefit Analysis (CBA), the returns on investments for salinity-based management are estimated as the net returns to oyster producers for three case study harvest areas Pambula Lake, Cromartys Bay (Port Stephens) and Wapengo Front Lake, during both drought and above average rainfall periods. Benefits to the environment and community are also discussed qualitatively in this report. This work builds on a previous assessment by NSW DPI (2021).

Results in Table 1 show that the net returns (or Net Present Value) to oyster producers, from the implementation of real-time sensors, are positive in both drought and above average rainfall periods for all three case studies. In Pambula Lake and Cromartys Bay above average rainfall periods decreased returns to the harvest area by about 7 and 41 percent respectively, however, revenue was 26 percent greater in Wapengo Front Lake. The sensitivity analysis maintains a positive return on

investment in scenarios with 3 percent and 7 percent discount rates and increased costs from sensor failure.

The return to farm gate value (or gross value of production) from the use of real-time sensors is on average estimated at 3 to 9 percent across the three case study areas. While this study shows that there are measurable returns from the use of this technology the magnitude of benefit is likely to vary with:

- variability in individual catchment areas.
- variability in future climate conditions and seasonality that may be region specific.
- incentives to adopt and manage a new technology. These estimates are a guide of the potential returns that may be realised in any catchment area.

Table 1 CBA results estimated in 2020-21 dollars ($/hectare)

Catchment area	Drought[1]			Above average rainfall[2]		
	Annualised Net Present Value		Benefit Cost Ratio	Annualised Net Present Value		Benefit Cost Ratio
	Returns per hectare ($/ha)	Returns to harvest areas ($/area)		Returns per hectare ($/ha)	Returns to harvest areas ($/area)	
Pambula Lake	1,923	116,679	2.12	1,562	108,353	2.14
Cromartys Bay[3]	1,121	15,923	1.52	549	9,375	1.45
Wapengo Front Lake	1,416	37,774	1.88	1,784	47,611	1.97

Note: 1. Drought periods are 2016-17 to 2019-20 for Pambula Lake, 2017-18 to 2019-20 for Cromartys Bay and 2018-19 to 2019-20 for Wapengo Front Lake; 2. Above average rainfall compared to historical records occurred in 2020-21 to 2021-22 for all case study areas (BOM 2023); 3. Harvest and depuration is also used in Cromartys Bay, however, it was found to have no significant impact on CBA results in NSW DPI (2021) and so is not assessed in this CBA.

A range of social and environmental benefits have resulted from the volume of real-time data recorded by sensors. Increasing estuary data improves:

- the **condition of estuaries** (i.e., pollution sources) by supporting remediation activities and enhancing knowledge of contamination events
- **public awareness** of estuary condition and environmental impacts
- **food safety** that supports the production of safer food in Australia for the domestic and export market, research into food safety
- support for **business and stock management,** increasing returns to producers and industry expansion into the future.

Consideration was also given to two estuaries — Hawkesbury River, and Shoalhaven and Crookhaven Rivers — as these estuaries have been significantly challenged during above average rainfall events. However, due to limited data these estuaries were not formally assessed.

This analysis shows that salinity-based management plans can improve net returns to oyster producers. Given the ongoing multiple adverse conditions in recent years including, bushfires, flooding, oyster disease and disruptions from the COVID-19 pandemic, this technology provides producers with management tools to remain viable, with more opportunities to harvest and avoid risks associated with holding stock.

1. Background

To minimise the risk of potential contaminants and maintain food safety standards for commercial oyster production, harvesting is prohibited following heavy rainfall. In most classified commercial oyster aquaculture areas in NSW, rainfall-based management plans are currently used to close harvest areas. The use of sensors that record salinity can provide data to refine harvest area management plans.

Access to live and real-time data facilitates improved risk management for shellfish harvest, particularly due to the high temporal frequency of data available. Food safety management plans have evolved based on sensor data to consider salinity trends, rather than point-in-time measurements. Live sensor data can result in more efficient farm operations and stock handing for producers. Further, it increases the ability of industry to avoid the increasing risk of environmentally related disease events to access more harvest opportunities and to sell stock before known disease windows.

The 2021-2024 Food Agility CRC Transforming Australian Shellfish Production Project is supporting the adoption of and use of data (salinity, temperature and water height) from real-time sensors in fifteen NSW oyster producing estuaries and one developing aquaculture zone in Western Australia. Application of this technology is being developed as part of a collaboration between the Food Agility Cooperative Research Centre, University of Technology Sydney (UTS) and the NSW DPI (Aquaculture Research and Biosecurity and Food Safety), NSW Farmers Association and the Western Australia Agriculture Authority, along with NSW and WA oyster farmers.

In Phase 1, Pambula Lake and Cromartys Bay harvest areas were early adopters of the salinity-based management plans. An economic assessment was conducted by NSW DPI (2021) to quantify the returns for the oyster industry in these locations. This phase was completed in early 2021.

To date, the project has demonstrated proof of concept of the potential to use salinity-based management plans in lieu of traditional rainfall-based plans in eighteen harvest areas across the thirteen[1] NSW estuaries included in Phase 1. Six salinity-based harvest area management plans have been adopted by the shellfish industry to date[2]. Phase 2 is building on the work of Phase 1 and includes two[3] additional NSW estuaries, and refinement of molecular based tools to track potential pollution sources (human, bird, cattle) in biological samples collected during Phase 1. Estuary specific reports are being developed for each participating location and include modelling of sensor data relative to findings of pollution source tracking and oyster growth data.

[1]Hastings River, Camden Haven, Manning River, Wallis Lake, Port Stephens, Hawkesbury River, Georges River Shoalhaven and Crookhaven Rivers, Clyde River, Wagonga Inlet, Wapengo Lake, Pambula River, Wonboyn Lake.

[2]Pambula River (Pambula Lake), Port Stephens (Cromartys Bay), Hawkesbury River (Coba Bay and Marramarra), Manning River (Pelican Point), Wapengo Lake (Front Lake).

[3]Macleay River and Merimbula Lake.

2. Methodology

This cost benefit analysis is used to estimate the net benefits (or Net Present Value (NPV)) and returns on investment (or BCR) of adopting real-time sensors and salinity-based harvest area management plans for oyster production in NSW.

An ex-post CBA is undertaken in this analysis as the impacts have occurred and we are estimating the actual benefits and costs. This CBA is in line with the NSW Treasury CBA guidelines (TPG23-08) and quantifies as many benefits and costs as possible and then assesses the qualitative impacts.

The net benefits of using real-time sensors and a salinity-based management plan in oyster production are estimated relative to the net benefits of production using a traditional rainfall-based management plan. Results reported include the annualised NPV and BCR.

The focus of this CBA is to assess three of the six harvest areas that have adopted salinity-based management plans: Pambula Lake, Cromartys Bay and Wapengo Front Lake — during the drought and years of above average rainfall (Appendix A).

Other estuaries that were considered for assessment in this CBA include Hawkesbury River and Shoalhaven and Crookhaven Rivers, as these estuaries have been significantly challenged during above average rainfall events. A comprehensive assessment of both estuaries was not undertaken in this CBA due to the lack of data during the above average rainfall period. Hawkesbury River oyster farmers have adopted the salinity-based management plan in two harvest areas. The Hawkesbury River program is supported by Hornsby Shire Council's Estuary Water Quality Monitoring Program, and is expected to provide positive benefits in the future to oyster producers in the Hawkesbury River. Waterways like Shoalhaven and Crookhaven Rivers, with complex catchments and hydrology, will require longer datasets to fully utilise the benefits of real-time sensors.

a. Measuring benefits and costs

Impacts that are estimated in this CBA include:

- **Benefits** the additional revenues from using real-time information to increase the number of harvest days in individual harvest areas.

  Additional revenue is estimated as the quantity of additional production, from additional harvest days, times the average farm gate price. These quantity and price data are averaged across the drought and above average rainfall periods.

  It is assumed that the above average rainfall years occurred in 2020-21 to 2021-22 for all case study areas and the drought period is in 2017-18 to 2019-20 for all case study areas, except Pambula Lake that commences in 2016-17.

- **Costs** per hectare to oyster producers to increase the harvesting of output and the annual cost to maintain, install and replace sensors.

A summary of the data used to estimate these values is provided in Appendix A to D.

A qualitative analysis is also incorporated in Section 3 to outline the environmental and community benefits of real-time sensors in harvest areas.

3. Results

a. Annualised value of quantitative net returns

A comprehensive summary of the quantified results is provided in Table 2 below.

Results in Table 2 show that the net returns (or NPV) to oyster producers, from the implementation of remote sensors, are **positive in both drought and above average rainfall periods for all three case studies**. That is, the present value of benefits (PVB) from additional harvest opportunities outweighs the present value of costs (PVC).

The net returns to production, for both Pambula Lake and Cromarty Bay, are greater in a drought than above average rainfall events, as the use of real-time sensor and salinity-based management allows the harvest area to be open for longer. There are additional harvest days during heavy rainfall periods, but the harvest area is more likely to be closed for longer in these years. However, in Wapengo Front Lake net returns are greater in periods of above average rainfall as compared with drought periods due to extra harvest days gained in 2021-22.

The return to farm gate value (or gross value of production) from the use of real-time sensors is on average estimated at 3 to 9 percent across the three case study areas. These estimates are a guide of the potential returns that may be realised in any catchment area.

While this study shows that there are measurable returns from the use of this technology the magnitude of benefit is likely to vary with:

- variability in individual catchment areas.
- variability in future climate conditions and seasonality that may be region specific.
- incentives to adopt and manage a new technology.

Future climate projections are variable, and the potential increasing frequency of hotter days and heavy rainfall can be region specific (Adapt NSW 2023). The value of using real-time sensors in oyster harvest areas may advance further to include algorithms that assess trends from live data feeds, to provide more insight and support for operational decisions. Sensor data can be coupled with other operational tools (e.g., Harvest and Hold (NSW Food Authority 2020) and wet storage (NSW Food Authority 2023)) to maximise continuity of supply.

Consideration was also given to two estuaries — Hawkesbury River and Shoalhaven and Crookhaven Rivers — as these estuaries have been significantly challenged during above average rainfall events. However, due to limited data these estuaries are not fully assessed.

Table 2 PVB, PVC, NPV and BCR[1] by harvest area for the drought and above average rainfall periods (in 2021-22 dollars)

Scenario/Economic measures	Drought				Above average rainfall			
	PVB	PVC	NPV	BCR[4]	PVB	PVC	NPV	BCR
1. Returns per hectare ($/ha)								
Pambula Lake	3,642	1,719	1,923	2.12	2,934	1,372	1,562	2.14
Cromartys Bay	3,264	2,142	1,121	1.52	1,778	1,229	549	1.45
Wapengo Front Lake	3,021	1,606	1,416	1.88	3,621	1,837	1,784	1.97
2.Returns to harvest areas ($/area)								
Pambula Lake	220,993	104,313	116,679	2.12	203,572	95,220	108,353	2.14
Cromartys Bay	46,341	30,417	15,923	1.52	30,383	21,008	9,375	1.45
Wapengo Front Lake	80,628	42,854	37,774	1.88	96,633	49,022	47,611	1.97

Note: 1. PVB = Present Value of Benefits, PVC = Present Value of Costs, NPV = Net Present Value and BCR = Benefit to Cost Ratio.

b. Qualitative Environmental and Social Benefits

A range of environment and social benefits have resulted from the implementation of real-time sensors in oyster aquaculture areas. These include:

- **Environmental impacts** — Coastal environments are the receiving waters for flood and storm runoff, with issues such as marine debris, pollutants and nutrient influx having substantial water quality impacts. Data collected during the project can assist understanding of pollution sources (faecal source tracking) to promote shoreline remediation and enhance knowledge regarding the modelling and prediction of contamination events (see Ajani et al. 2022a-e, 2023). The preparation of individual estuary reports for participating NSW estuaries is ongoing (Food Agility CRC 2023).
- **Human health and net returns to business** — continued use of the real-time sensor data provides producers with improved information to support better business and stock management. These benefits will be realised with increased used of the technology, which can increase net returns to producers and reduce work related stress (NSW DPI 2021).
- **Safe and secure food supply** — Management of potential health risks through newer technology supports and promotes the reputation of NSW primary produce as safe and high quality. Safer food is a reduced burden on the health system. The project data provides information that feeds into local and state government policy of water quality and estuary management; this results in better food security. This in turn supports domestic and export market access for NSW primary produce/shellfish, feeding into investor confidence in NSW aquaculture. This aligns with NSW DPI Stronger Primary Industries Strategy 2022-30 (NSW DPI 2022) and the strategic outcomes for food safety and economic growth.
- **Industry development** — The project data has supported the development of rapid molecular testing in the food safety space (see Ajani et al. 2022a-e, 2023). Faster, more accurate testing has the potential to be used on-site and can prevent expensive product recalls. Transfer of knowledge to other aquaculture sectors e.g.,

Storm and Flood Industry Recovery Program Aquaculture projects (Regional NSW 2022) to develop more sustainable management practices and industry expansion.

- **Engaging citizen scientists** — More than 8,000 water samples and 4,000 oyster samples were collected, targeting eDNA samples weekly, for over two years by citizen science oyster farmers. This analysis is not on-going and is independent of the quantitative analysis in this paper. Worldwide, this is the largest dataset of water quality and health measurements from oyster-producing estuaries (UTS 2022a). The data was collected through flood, drought, bushfires, algal blooms, storms and tsunami scenarios, adding to its uniqueness.
- **Knowledge sharing –** There was a high demand for the data outside of the main project (pers.com. Ajani & Murray 2023) to support projects and developing research relating to harmful algae, oyster disease, marine ecology, emerging food safety issues and pollution source tracking:
  - >20 research projects (internal and external)
  - >20 oral presentations (academic and industry focused)
  - 7 Hons/MSc/PhD research students
  - 6 Peer reviewed journal articles have been produced (Ajani et al. 2020, 2021, 2022f, Barua et al. 2020, Lenzen et al 2021, McLennan et al. 2021).
- **Engagement –** Public awareness of the project was highlighted through:
  - 12 News/media articles, including a "story on the oyster industry's battle to recover after a series of natural disasters and put oysters on the menu for Christmas had 114 placements with an estimated total audience of just under 68,000" (pers.com. UTS 2022)
  - 4 online videos (>950 views) (CNBC 2017, Food Agility 2019, 2020a,b)
  - The main project website (Food Agility 2023), had 270 unique page views between March 2021 and February 2023 (https://www.foodagility.com/research/transforming-australian-shellfish-production)
  - The previous economic assessment webpage (NSW Food Authority 2021) had 197 unique page views between January 2021 and February 2023. (https://www.foodauthority.nsw.gov.au/about-us/science/science-in-focus/real-time-sensors-shellfish-harvest-area-management)
  - UTS EResearch platform developed for data access and sharing: https://salinity.research.uts.edu.au/.

b. Sensitivity Analysis

Results of the sensitivity analysis are provided in Table 3, for the following three scenarios:

- discount rate of 3 percent
- discount rate of 7 percent, as per NSW Treasury CBA guidelines (TPG23-08)
- the entire sensor system is damaged and needs to be replaced within its 5-year life (Appendix D).

Table 3 shows that the NPVs and BCRs are positive for all scenarios and there is still a positive net benefit to implementing sensors.

Table 3 Results of sensitivity analysis

Scenarios	Drought			Above average rainfall		
	Annualised NPV[1]		BCR[2]	Annualised NPV[1]		BCR[2]
	($/ha)	($ per harvest area)		($/ha)	($ per harvest area)	
A. 3 percent discount rate						
Pambula Lake	1,697	102,996	2.12	1,488	103,244	2.14
Cromartys Bay	1,018	14,458	1.52	519	8,871	1.44
Wapengo Front Lake	1,314	35,077	1.88	1,702	45,425	1.97
B. 7 percent discount rate						
Pambula Lake	2,173	131,840	2.12	1,637	113,599	2.14
Cromartys Bay	1,233	17,506	1.52	579	9,895	1.45
Wapengo Front Lake	1,522	40,622	1.88	1,868	49,854	1.97
C. Sensor replaced within the first 5 years						
Pambula Lake	1,773	107,583	1.95	1,454	100,869	1.98
Cromartys Bay	679	$9,640	1.26	$231	3,948	1.15
Wapengo Front Lake	1,191	31,790	1.65	1,581	42,184	1.77

Note: 1. NPV = Net Present Value; 2. BCR = Benefit to Cost Ratio.

Appendices

Appendix A: Key data and assumptions

Table A1 Key data and assumptions

1. A discount rate of 5 percent is used for the base results; and 3 and 7 percent for the sensitivity analysis.
2. Main marketable season includes Christmas and Easter and harvest opportunities between drought and above average rainfall time categories were considered:
    - Pambula Lake: December to July
    - Cromartys Bay: December to June
    - Wapengo Front Lake: December to July
3. Oyster production and harvest opportunities were estimated across the following drought and above average rainfall categories:

Harvest area	Drought	Above average rainfall
Pambula Lake[1]	2016-17[2] to 2019-20	2020-21 to 2021-22
Cromartys Bay	2017-18 to 2019-20	2020-21 to 2021-22
Wapengo Front Lake	2018-19 to 2019-20	2020-21 to 2021-22

Note: 1. Time period for Pambula Lake is longer due to earlier adoption of sensor technology; 2. 2016-17 climate data were variable, but conditions were not consistently reported within the non-drought category as per data from 2020 onwards. 2016-17 harvest opportunities were comparable to other drought category years (2017-18 to 2019-20) in Pambula Lake.

4. Net revenue estimates are valued in 2021-22 dollars using the ABS (2022) CPI data.
5. The number of businesses (i.e., permit holders) is 28 in Pambula Lake, 8 in Cromartys Bay and Wapengo Front Lake.
6. Harvest areas considered in the current report

Estuary	Harvest area	Harvest system
Pambula River	Pambula Lake	Direct Harvest
Port Stephens	Cromartys Bay	Direct Harvest and Harvest and Depuration
Wapengo Lake	Wapengo – Front Lake	Direct Harvest
Hawkesbury River[1]	Coba Bay	Direct Harvest
Hawkesbury River[1]	Marramarra	Direct Harvest
Shoalhaven & Crookhaven Rivers[1]	Goodnight Island	Direct Harvest and Harvest and Depuration

Note: 1. not modelled for CBA but are included in discussion for context of variability experienced during above average rainfall.

Appendix B. Production and average farm gate prices (DPI Aquaculture Reports (2016-17 to 2021-22, NSW DPI 2023a)

Table B1. Pambula Lake – Sydney Rock Oyster commodity statistics 2016-17 to 2021-22

Data type	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
Production quantity (dozens)						
Large Grade	60,136	70,308	65,527	58,736	51,937	53,854
Medium Grade	111,201	135,126	142,271	135,429	118,656	104,692
Small Grade	75,174	75,512	56,968	79,073	85,290	76,718
Total	246,511	280,946	264,766	273,238	255,883	235,264
Average farm gate price ($/dozen)[1]						
Large Grade	9.74	10.65	11.15	11.31	10.67	11.87
Medium Grade	7.73	8.42	8.93	8.83	8.67	9.78
Small Grade	5.59	6.23	6.64	6.97	6.73	7.43
Average weighted farm gate price[1]	7.57	8.39	8.99	8.82	8.43	9.49

Note: 1. The analysis uses the weighted average farm gate price across grades for estimates.

Table B2 Cromarty Bay - Sydney Rock and Pacific Oyster commodity statistics 2017-18 to 2021-22

Data type	2017-18	2018-19	2019-20	2020-21	2021-22
1. SYDNEY ROCK OYSTERS					
Production quantity (dozens)[1]					
Large Grade	27,941	25,466	37,347	31,451	37,316
Medium Grade	18,351	19,436	22,789	29,005	32,343
Small Grade	14,894	16,714	19,356	25,731	26,908
Total	61,186	61,616	79,493	86,187	96,567
Average farm gate price ($/dozen)[2]					
Large Grade	10.65	11.15	10.85	11.00	11.38
Medium Grade	8.42	8.93	8.79	8.80	9.12
Small Grade	6.23	6.64	6.47	6.38	6.79
Average weighted farm gate price[2]	8.91	9.23	9.19	8.88	9.34
2. PACIFIC OYSTERS					
Production quantity (dozens)[1]					
Large Grade	859	120	476	149	58
Medium Grade	939	160	325	152	129
Small Grade	1,006	204	86	276	219
Total	2,805	483	887	576	405
Average farm gate price ($/dozen)[2]					
Large Grade	12.19	11.44	11.00	10.84	11.80
Medium Grade	9.97	10.01	10.23	9.27	10.33
Small Grade	7.62	8.80	8.00	7.60	9.08
Average weighted farm gate price[2]	9.81	9.86	10.43	8.88	9.87

Note: 1. Production estimates in the above table are estimated as a product of the total production in Port Stephens and the proportion of Cromarty Bays total harvest area relative to that in Port Stephens; 2. The analysis uses the weighted average farm gate price across grades for estimates.

Table B3. Wapengo Front Lake Sydney Rock Oyster commodity statistics 2018-19 to 2021-22

Data type	2018-19	2019-20	2020-21	2022-22
Production quantity (dozens)[1]				
Large Grade	23,296	17,338	28,193	18,705
Medium Grade	45,547	37,262	33,814	64,595
Small Grade	32,950	27,624	23,003	32,498
Total	101,794	82,225	85,009	115,799
Average farm gate price ($/dozen)[2]				
Large Grade	11.93	12.64	11.61	13.27
Medium Grade	9.23	10.08	9.29	10.95
Small Grade	7.10	7.53	7.04	8.18
Average weighted farm gate price[2]	9.16	9.76	9.45	10.55

Note: 1. Production estimates in the above table are estimated as a product of the total production in Wapengo Lake and the proportion of Wapengo Front Lake total harvest area to Wapengo Lake; 2. Note that the analysis uses the weighted average farm gate price across grades for estimates.

Appendix C Harvest area statistics

Table C1. Key statistics of the three modelled harvest areas (NSW DPI Unpublished data)

	Pambula Lake	Cromartys Bay	Wapengo – Front Lake	Unit
A. Drought				
Current harvest area	60.68	14.20	26.69	ha
Maximum potential harvest area	96.32	49.30	35.58	ha
B. Above average rainfall				
Current harvest area	69.39	17.10	26.69	ha
Maximum potential harvest area	96.04	51.40	35.58	ha

Source: pers.com. NSW DPI (2023).

Table C2. Number of additional direct harvest days by harvest area based on sensor use.

Harvest area	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
Pambula Lake	17	19	12	1.5	24.25	0.25[1]
Cromarty Bay	N/A	11	7	9	10	0
Wapengo Front Lake	N/A	N/A	9	12	23	2

Note: 1. The current Pambula Lake management plan has been further refined to decrease the salinity limit based on newer data. Some previous harvest area closures may not have occurred based on this limit.

Appendix D. Cost of inputs in production and sensors

The cost of installing the sensors is estimated at $8,000 (spread over five years) and annual maintenance of sensors is estimated at $5,000. Note these costs are cheaper for Pambula Lake as the costs are spread across 28 businesses compared to 8 businesses in both Cromartys Bay and Wapengo Front Lake.

Table D1 - Average production cost per dozen oysters in NSW farms[1]

Item		Input costs of by % (% of GVP[2])
FIXED COSTS		
1. Paying annual levy to Government		
a. Fisheries		0.6%
b. NSW Food Authority		
	Pambula Lake	3.3%
	Cromartys Bay	5.3%
	Wapengo Front Lake	3.3%
c. Crown Lands		1.0%
2. Water-based capital replacement		4.2%
3. Land-based and water plant and equipment replacement		3.0%
4. Insurance		0.3%
VARIABLE COSTS		
5. Annual spat purchase or on-farm catching		2.2%
6. Labour		24.6%
7.Maintenance		1.5%
8. Expendables (power, fuel, single use lease components such as boxes, bags, cable ties)		2.5%

Note: 1. Based on a representative suite of farmers with an existing and developed farm in NSW. Source: pers.com. NSW DPI (2023); 2. GVP = Gross Value of Production.

Appendix E. Estimation of drought and above average rainfall periods

The Australian Bureau of Meteorology (BOM) provides annual state climate summaries, and trends were examined between 2016 and 2022 for NSW (BOM, 2023). Weather patterns during 2016 were highly variable throughout the year and state was generally wet and warm. Between 2017 and 2019, records indicated a period of progressive warming, with 2019 being the driest year on record for NSW. From 2020 onwards, wetter conditions occurred, with notable increases in average rainfall when compared to historical records (e.g., 2021, rainfall 30% above average and 2022 annual rainfall was reported within the top 10% since 1900).

Data from the NSW DPI Enhanced Drought Information System II (EDIS II)/NSW DPI Seasonal Conditions Portal (NSW DPI, 2023b), was reviewed for each of the case study locations to distinguish between periods of drought and non-drought. The Combined Drought Indicator (CDI) gives a snapshot of seasonal conditions including rainfall, soil moisture and modelled pasture/crop growth indices. The tool categorises an area to be in drought if any of the indices fall below 30% relative to historical data. Table E1 summarises CDI information for each of the case study locations. In the case of the non-drought periods from 2020 onwards, this coincided with above average wet weather conditions as noted earlier, and subsequent flooding.

Table E1. Summary of case study locations and CDI information used to distinguish consistent non-drought periods (NSW DPI, 2023b).

Estuary	Harvest area	Parish(es)	County	Combined Drought Indicator (CDI): consistent non-drought
Port Stephens	Cromartys Bay	Tomaree	Gloucester	Nov 2020 - current
Wapengo Lake	Wapengo Front Lake	Wapengo, Tanja	Dampier	Nov 2020 - current
Pambula River	Pambula Lake	Yowaka, Pambula	Auckland	Nov 2020 - current

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References

ABS (2022). Consumer Prices Index, Australia https://www.abs.gov.au/statistics/economy/price-indexes-and-inflation/consumer-price-index-australia/latest-release viewed March 2023.

Adapt NSW (2023). Interactive climate change projections map. https://www.climatechange.environment.nsw.gov.au/projections-map.

Ajani et al. (2020). Fifteen years of *Pseudo-nitzschia* in an Australian estuary, including the first potentially toxic *P. delicatissima* bloom in the southern hemisphere. Estuarine, Coastal and Shelf Science. 236:106651. doi:10.1016/j.ecss.2020.106651

Ajani et al. (2021). Using qPCR and high-resolution sensor data to model a multi-species *Pseudo-nitzschia* (Bacillariophyceae) bloom in Southeastern Australia. Harmful Algae. 108:102095. doi: 10.1016/j.hal.2021.102095.

Ajani et al. (2022a). Transforming Australian Shellfish Production: Pelican Point Harvest Area, Manning River. Report on Stage 1, October 2017-March 2021. 46pp. https://assets-global.website-files.com/5f4f19737a6ae318c84e362c/625659feb0eed1b0d5febcaa_Manning%20River%20Report_Final%202022%20v1.pdf

Ajani et al. (2022b). Transforming Australian Shellfish Production: Lower Honeymoon Bay Harvest Area, Wagonga Inlet. Report on Stage 1, October 2017-March 2021 54pp. https://assets-global.website-files.com/5f4f19737a6ae318c84e362c/62b2661773985626d2ef01af_Wagonga%20Inlet%20Report_Final.pdf

Ajani et al. (2022c). Transforming Australian Shellfish Production: Long Island Harvest Area, Wallis Lake. Report on Stage 1, October 2017-March 2021 48pp. https://www.foodagility.com/posts/transforming-australian-shellfish-production-long-island-harvest-area-wallis-lake

Ajani et al. (2022d). Transforming Australian Shellfish Production: Goodnight Island Harvest Area, Shoalhaven and Crookhaven Rivers. Report on Stage 1, October 2017-March 2021 47pp. https://assets-global.website-files.com/5f4f19737a6ae318c84e362c/636c786594e0551f91c31ede_Shoalhaven%20Report_FINAL.pdf

Ajani et al. (2022e). Transforming Australian Shellfish Production: Pambula Lake Harvest Area, Pambula River. Report on Stage 1, October 2017-March 2021 48pp. https://assets-global.website-files.com/5f4f19737a6ae318c84e362c/6389742627f32e4b275d641c_Pambula%20Report_FINAL.pdf

Ajani et al. (2022f). Mapping the Development of a *Dinophysis* Bloom in a Shellfish Aquaculture Area Using a Novel Molecular qPCR Assay. Harmful Algae. 116:102253. doi: 10.1016/j.hal.2022.102253.

Ajani et al. (2023). Transforming Australian Shellfish Production: Quibray Bay Harvest Area, Georges River. Report on Stage 1, October 2017-March 2021 55pp. https://assets-global.website-files.com/5f4f19737a6ae318c84e362c/6405535e7a29d07b1a322c26_Transforming%20Australian%20Shellfish%20Production%20-%20Georges%20River.pdf

Barua et al, (2020). First detection of paralytic shellfish toxins from *Alexandrium pacificum* above the regulatory limit in Blue Mussels (*Mytilus galloprovincialis*) in New South Wales, Australia. Microorganisms. 8(6):905. doi:10.3390/microorganisms8060905

Bureau of Meteorology (BOM) (2023). Climate Summaries Archive (2023). http://www.bom.gov.au/climate/current/statement_archives.shtml?region=nsw&period=annual (accessed 17 February 2023)

CNBC (2017). One of the Most Sustainable Farming Enterprises Meets Hi-tech. https://www.cnbc.com/video/2017/03/05/one-of-the-most-sustainable-farming-enterprises-meets-hi-tech.html

Food Agility CRC (2019). PROJECT NEWS: Can World Leading Research Transform the NSW Oyster Industry? https://www.youtube.com/watch?v=cfAyjjnASy0&t=154s

Food Agility CRC (2020a). Food Agility Summit 2020: WE LOVE SCIENCE! https://www.youtube.com/watch?v=iRcRZkptpOY&t=46s

Food Agility CRC (2020b). Food Agility CRC – Cooperative Research Centre Customer Story. https://www.youtube.com/watch?v=4NM_U_lKCEE&t=1s

Food Agility CRC (2023). Transforming Australian Shellfish Production. https://www.foodagility.com/research/transforming-australian-shellfish-production

Lenzen et al. (2021). Impacts of Harmful Algal Blooms on Marine Aquaculture in a Low-Carbon Future. Harmful Algae. 110:102143. doi: 10.1016/j.hal.2021.102143.

McLennan et al. (2021). Assessing the Use of Molecular Barcoding and qPCR for Investigating the Ecology of *Prorocentrum minimum* (Dinophyceae), a Harmful Algal Species. Microorganisms. 9(3):510. doi: 10.3390/microorganisms9030510.

NSW DPI (2021). Net Returns of Real-Time Sensors and Salinity-Based Management Plans in NSW Oyster Production. 15pp. https://www.foodauthority.nsw.gov.au/sites/default/files/2021-03/FINAL_Oyster%20Realtime%20Sensors%20CBA%20Short%20Report%204%20March%202021.pdf

NSW DPI (2022). NSW DPI Strategic Plan 2022-2030. https://www.dpi.nsw.gov.au/about-us/publications/nsw-dpi-strategic-plan-2022-2030

NSW DPI (2023a). Aquaculture Production Reports (2017-18 to 2021-22). https://www.dpi.nsw.gov.au/fishing/aquaculture/publications/aquaculture-production-reports

NSW DPI (2023b). Seasonal Conditions Portal. https://edis.spaceport.intersect.org.au/%2FDroughtHistory%2FParish (accessed 6 February 2023)

NSW Food Authority (2020). NSW Shellfish Program Harvest and Hold Scheme. 9pp. https://www.foodauthority.nsw.gov.au/sites/default/files/2020-09/NSW-shellfish-program-harvest-and-hold-scheme.pdf

NSW Food Authority (2021). Real-time Sensors for Shellfish Harvest Area Management. https://www.foodauthority.nsw.gov.au/about-us/science/science-in-focus/real-time-sensors-shellfish-harvest-area-management

NSW Food Authority (2023). Food Safety and Biosecurity Guidelines for Wet Storage of Shellfish at Wholesale 2pp. https://www.foodauthority.nsw.gov.au/sites/default/files/2023-02/food-safety-and-biosecurity-guidelines-wet-storage-shellfish-wholesale.pdf

NSW Treasury (2023). TPG23-08 NSW Government Guide to Cost-Benefit Analysis. 116pp. https://www.treasury.nsw.gov.au/finance-resource/guidelines-cost-benefit-analysis

Regional NSW (2022). Sector Recovery and Resilience Grant. https://www.nsw.gov.au/regional-recovery-programs/storm-and-flood-recovery/sector-recovery-and-resilience-grant#toc-aquaculture

University of Technology (UTS) Sydney (2022). Transforming the Oyster Industry. https://www.uts.edu.au/research-and-teaching/research/explore/impact/transforming-oyster-industry