Environmental Implementation Committee 7 November 2024

Meeting will be held in the Council Chamber at Level 2, Philip Laing House
144 Rattray Street, Dunedin
ORC Official YouTube Livestream

Members:
Cr Kate Wilson (Chair)
Cr Alexa Forbes
Cr Gary Kelliher
Cr Lloyd McCall
Cr Michael Laws
Cr Kevin Malcolm
Cr Tim Mepham
Cr Andrew Noone
Cr Gretchen Robertson
Cr Alan Somerville
Cr Elliot Weir

Senior Officer: Richard Saunders, Chief Executive

Meeting Support: Kylie Darragh, Governance Support Officer

07 November 2024 09:00 AM

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Agenda 1

1. WELCOME

2. APOLOGIES

No apologies were received prior to publication of the agenda.

3. PUBLIC FORUM

No requests to speak were received prior to the publication of this agenda.

4. CONFIRMATION OF AGENDA

Note: Any additions must be approved by resolution with an explanation.

5. DECLARATION OF INTERESTS

Members are reminded of the need to stand aside from decision-making when a conflict arises between their role as an elected representative and any private or other external interest they might have. Councillor Declarations of Interests are published to the ORC website.

6. PRESENTATIONS

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Confirming the minutes of the Environmental Implementation Committee of 8 August 2024.

8. OPEN ACTIONS FROM RESOLUTIONS OF THE COMMITTEE

There are currently no open actions for this committee.

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9.1 Freshwater Improvement Projects Update 6

This report provides an update on a number of water quality focused projects that ORC is involved in. These projects include the three ORC priority water quality projects: Tomohaka/Tomahawk Lagoon, Lake Tuakitoto and Lake Hayes/Waiwhakaata; an update on the Ministry for the Environment (MfE) funded Toitū Te Hakapupu/ Pleasant River Catchment Restoration project and the Ministry for Primary Industries (MPI) funded Hill Country Erosion project.

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To provide an update on work undertaken in response to the notification of an incursion of exotic freshwater clam species (Corbicula fluminea and Corbicula australis) into the North Island of New Zealand Aotearoa.

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10. CLOSURE

Environmental Implementation Committee
MINUTES

Minutes of an ordinary meeting of the Environmental Implementation Committee held in the Council Chamber, Level 2 Philip Laing House, 144 Rattray Street, Dunedin on Thursday 8 August 2024, commencing at 10:00 AM.

PRESENT

Cr Bryan Scott	*(Chair)*
Cr Alexa Forbes	
Cr Gary Kelliher	*(online)*
Cr Michael Laws	
Cr Kevin Malcolm	
Cr Lloyd McCall	
Cr Tim Mepham	
Cr Andrew Noone	
Cr Gretchen Robertson	
Cr Alan Somerville	
Cr Elliot Weir	
Cr Kate Wilson	

1. WELCOME

Chair Bryan Scott welcomed Councillors, members of the public and staff to the meeting at 10:01am with a karakia. Staff present included Richard Saunders (Chief Executive), Nick Donnelly (GM Finance) online, Anita Dawe (GM Planning and Transport), Joanna Gilroy (GM Environmental Implementation), Tami Sargeant (GM People and Corporate) Kylie Darragh (Governance Support), Anna Molloy (Principal Advisor Environmental Implementation), Libby Caldwell (Team Leader Environmental Implementation), Elodie Letendre (Environmental Initiatives Funding Coordinator).

2. APOLOGIES

Resolution: Cr Scott Moved, Cr Forbes Seconded:
That the apologies for Cr Robertson for lateness be accepted.
MOTION CARRIED

3. PUBLIC FORUM

Rebecca Shepherd (CEO) and Grant Dodson (Chair) spoke to the Committee in public forum on behalf of the Southern Wood Council, there was an opportunity for questions from Councillors, Chair Scott thanked both for attending and speaking to the Committee.

Cr Weir joined the meeting online at 10:12am.
Cr Somerville left the meeting at 11:00 am.
Cr Somerville returned to the meeting at 11:01 am.

4. CONFIRMATION OF AGENDA

It was moved by Cr Scott and seconded by Cr Wilson
***That** the agenda be confirmed as published.*
MOTION CARRIED

5. DECLARATIONS OF INTERESTS

No changes to Councillor Declarations of Interests were noted.

6. PRESENTATIONS

No presentations were held.

7. CONFIRMATION OF MINUTES

Resolution: Cr Scott Moved, Cr Wilson Seconded
That the minutes of the 8 &23 May 2024 Environmental Implementation Committee be received and confirmed as a true and accurate record.
MOTION CARRIED

8. OPEN ACTIONS FROM RESOLUTIONS OF THE COMMITTEE

There are currently no open actions for this Committee.

Cr Robertson joined the meeting at 10:58 am.
Cr Somerville left the meeting at 11:00 am.
Cr Somerville returned to the meeting at 11:02 am.
Cr Laws left the meeting at 11:04 am.
Cr Laws returned to the meeting at 11:05 am.

9. MATTERS FOR CONSIDERATION

9.1. Biodiversity Partnerships and Initiatives Update

(YouTube 34:55) This report provided an update on the environmental initiatives supported, and biodiversity partnerships and projects, as per the Annual Plan 2023-2024 level of service performance measures. Anna Molloy (Principal Advisor - Environment Implementation) online, and Libby Caldwell (Team Leader Environmental Implementation), Elodie Letendre (Environmental Initiatives Funding Coordinator) and Joanna Gilroy (GM Environmental Delivery) were present to respond to any questions.

Resolution EIC24-113: Cr Wilson Moved, Cr Somerville Seconded
That *the Environmental Implementation Committee:*

1. ***Notes*** *this report.*

MOTION CARRIED

9.2. Biosecurity Operational Plan Annual Report 2023-2024

(YouTube 1:04:30) This report was provided on the implementation of the Biosecurity Operational Plan 2023-24 for the period 1 July 2023 to 30 June 2024, as required under Section 100C(2) of the Biosecurity Act 1993. Murray Boardman (Performance and Delivery Specialist), Libby Caldwell (Manager Environmental Implementation), and Jo Gilroy (General Manager Environmental Delivery) were available to respond to questions.

Cr Weir left the meeting at 11:21am

Resolution EIC24-114: Cr Laws Moved, Cr Wilson Seconded
That *the Environmental Implementation Committee:*

1. ***Notes*** *this report and the range of work undertaken to give effect to Otago's Regional Pest Management Plan and the Biosecurity Act (1993).*
2. ***Notes*** *the lessons learnt from the 2023-24 Biosecurity Operational Plan are being applied to the delivery of the 2024-25 Biosecurity Operational Plan.*
3. ***Notes*** *that this report and the attached Biosecurity Operational Plan 2023-24 Report will be provided to the Minister for Biosecurity as required under Section 100C(2) of the Biosecurity Act 1993.*

MOTION CARRIED

12. CLOSURE

There was no further business and Chair Scott declared the meeting closed at 11:34am with a karakia.

_________________________ _________________

Chairperson Date

9.1. Freshwater Improvement Projects Update

Prepared for:	Environmental Implementation Committee
Report No.	GOV2429
Activity:	Governance Report
Author:	Libby Caldwell, Manager Environmental Implementation; Melanie White, Project Delivery Specialist – Jobs for Nature; Sarah Irvine, Team Leader Project Delivery; Alison Turner, Land Management Advisor
Endorsed by:	Joanna Gilroy, General Manager Environmental Delivery
Date:	7 November 2024

PURPOSE

[1] This report provides an update on a number of water quality focused projects that ORC is involved in. These projects include the three ORC priority water quality projects: Tomohaka/Tomahawk Lagoon, Lake Tuakitoto and Lake Hayes/Waiwhakaata; an update on the Ministry for the Environment (MfE) funded Toitū Te Hakapupu/ Pleasant River Catchment Restoration project and the Ministry for Primary Industries (MPI) funded Hill Country Erosion project.

EXECUTIVE SUMMARY

[2] Council is involved in the delivery of, or supporting the delivery of a number of water quality driven projects across the region. This paper provides an update on these projects since the last update in May 2024.

[3] The Long-Term Plan 2021-2031 detailed that key projects for delivery under environmental enhancement were the priority site specific projects of Lake Hayes, Tomohaka/Tomahawk Lagoon and Lake Tuakitoto.

a) Tomohaka/ Tomahawk Lagoon and Lake Tuakitoto Projects are progressing and detailed action plans have been developed to deliver the final stages of the programmes. This will ensure that previous budget underspends is spent during the 2024/25 financial year. Some adjustments have been made to activity completion dates.

b) In the Waiwhaata/Lake Hayes project, the Mill Creek (Arrow River water) augmentation works are nearing completion. The physical pipe infrastructure is all in place and sediment that has built up over time around the structure which discharges to Mill Creek is to be removed prior to commissioning the pipe.

[4] The Toitū Te Hakapupu project is funded through Ministry for the Environment (MfE) Essential Fresh Water Fund (EFF). ORC contributes money as an in-kind contribution and landowners contribute 25% of the value of the works on their property. Since the last update, the project team have liaised with Puketeraki and East Otago Catchment Group to seek a facilitator to complete succession planning for the project. Three sites in the catchment have been selected for willow control to support improvements in water

quality and in-stream habitat. There are currently 13 active planting and fencing sites and 36 landowners have been engaged with.

[5] The Hill Country Erosion project is a partnership between the Ministry for Primary Industries/ Te Uru Rākau, Councils, and landowners. The project aims to identify and demonstrate existing effective erosion management practises and support landowners to adopt best practise erosion control and mitigation. Since the last update an internal technical advisory group (TAG) has been established to ensure project planning is informed by teams across ORC.

RECOMMENDATION

That the Committee:

1) ***Notes*** *this report.*

2) ***Notes*** *the progress of implementation activities that are occurring on the water quality projects delivered by ORC, partners and the community as detailed in this report.*

3) ***Notes*** *that the Toitū Te Hakapupu project is in its last year of delivery to successfully deliver on all the objectives of the MfE funding deed.*

4) ***Notes*** *the progress made on the MPI funded Hill Country Erosion project.*

BACKGROUND AND DISCUSSION

Tomohaka/Tomahawk Lagoon

[6] The Otago Regional Council Long Term Plan 2021-2031 detailed Tomohaka/Tomahawk Lagoon as a key project for delivery between 2021 to 2023. This funding has been carried over to the current financial year. A total of $260,000 has been allocated to this project.

[7] Tomohaka/Tomahawk Lagoon is located at the southern end of the Otago Peninsula. It consists of two shallow brackish water lagoons which are joined by a narrow channel and weir/gate structure and share a common sea outlet (refer to Figures 1 and 2). Tomohaka/Tomahawk Lagoon is a wildlife refuge of 33 hectares, managed by the Department of Conservation. The threatened plant species *Isolepis basilaris* grows on the margin of the lagoon. The area is important ecologically as it is defined as a marsh and less than 15% of original marshes remain in Otago.

Figure 1: The catchment for Tomohaka/Tomahawk Lagoon

Figure 2: Tomohaka/Tomahawk Lagoon

[8] Tomohaka/Tomahawk Lagoon is a regionally significant wetland habitat for waterfowl and waders with a variety of bird species present and is part of a chain of feeding habitats along the coast used by migrating birds. Tomohaka/Tomahawk Lagoon is also an important habitat for native fish and eels.

[9] Citizen Science water quality monitoring is undertaken by ECOtago monthly. ECOtago are a community group who are working to test and improve water quality within the catchment. Their results (found at tomahawkcitizenscience.com) indicate that turbidity, E. coli, nitrates and phosphate levels are all exceeding national guidelines. Cyanobacteria is also regularly found within the lagoon over the summer months which is a toxic bacterium which can be harmful to humans and animals.

[10] An update of progress from 2021 – May 2024 was presented to the Environmental Implementation Committee on 8 May 2024. Since this time, a detailed action plan has been developed to deliver the final stages of the programme through to June 2025 and ensure that previous budget underspend is spent during the 2024/25 financial year. Some adjustments have been made to dates to incorporate activities from the previous financial year (Table 1).

Table: 1 Summary of date changes for Tomohaka/Tomahawk Lagoon Action Plan

Activity	Previously endorsed delivery date	Proposed new delivery date
Work collaboratively with mana whenua, stakeholders, and community to develop final Implementation Plan	May 2024	December 2024
Discussions with ORC natural hazards and engineering to identify any risks of below activities	May 2024	October 2024 and as new sites are proposed
Develop and install signage to facilitate community education	No date noted	April 2025
Devise mechanisms to support education initiatives that contribute to the programme's Vision	May 2024	Partially completed. Final delivery in April 2025
Work with landowners to identify and prioritise areas in the catchment for habitat enhancement activities	May 2024	December 2024
Discuss cost-sharing mechanism and collaboration with the landowners and community	June 2024	January 2025
Wetland Construction Plan created	No date noted	May 2025
Implementation Plan and budget created	No date noted	June 2025

[11] In May 2024, a total of $12,600 funding was granted to ECOtago to deliver water quality monitoring and engagement at Tomahawk Lagoon through to 30th June 2025. To date, ECOtago have purchased equipment and carried out monthly monitoring with five local schools as planned. A reporting hui for the students and facilitators has been organised for 5th November 2024.

[12] In June 2024 ORC provided a total of $32,200 direct funding to Tomahawk-Smaills BeachCare Trust to deliver fencing and planting works to improve water quality. The Trust has reported good progress with the Lagoon Creek planting project with fencing of one site completed and the second scheduled for early 2025. To date, 1309 trees, shrubs, sedges, and grasses have been planted in the fenced area. Mulch mats and tree guards have been installed and are holding well given the exposure of the site to strong

winds. Approximately 100 volunteers have been involved in the project with schools and organisations involved in planting and a community planting day that was well-attended by over 60 people. Plant propagation for the 2025 season is on track.

Lake Tuakitoto

[13] The Otago Regional Council Long Term Plan 2021-2031 detailed Lake Tuakitoto as a key project for delivery between 2021 to 2023. This funding has been carried over to the current financial year A total of $260,000 has been allocated to this project.

[14] Lake Tuakitoto is a large lowland lake and adjoining swamp near the coast north of the Clutha River/Mata-Au Mouth (Figure 3). It is fed from the inflow of Lovells Creek at the northern end of the wetland and is the best remaining example in Otago of a previously widespread wetland type (ORC, 2004).

Figure 3: Map showing the catchment for Lake Tuakitoto.

[15] Lake Tuakitoto supports a high diversity of indigenous flora and fauna and an exceptionally high diversity of bird life. It is a regionally significant wetland habitat for nationally and internationally rare or threatened species. A diverse mosaic of vegetation

types and wildlife habitats exists within the Lake Tuakitoto area. It is considered a regionally and nationally important habitat for waterfowl, waders and swamp birds. It is considered nationally important as a freshwater fishery habitat.

[16] Lake Tuakitoto has significant cultural value for Kāi Tahu and includes mahika kai and waahi taoka sites. The associated wetland is highly valued by Kāi Tahu for its historical associations and as a traditional food gathering area (ORC, 2004).

[17] Lake Tuakitoto provides significant hydrological values including maintaining water quality and low flows or reducing flood flows. It serves as a flood ponding area and is an integral part of the Lower Clutha Flood Control and Drainage Scheme (ORC, 2004). The lakebed and some of the lake margins are owned by ORC. The opportunity exists for ORC, as a landowner, to enhance its land in the same way other landowners are enhancing theirs.

[18] An update of progress from 2021–May 2024 and a draft implementation plan were presented to the Environmental Implementation Committee on 8 May 2024. Since this time, a detailed action plan has been developed to deliver the final stages of the programme through to June 2025 and ensure that previous budget underspend is spent during the 2024/25 financial year. Some adjustments have been made to dates to incorporate activities from the previous financial year (Table 2).

Table 2: Summary of activity date changes to deliver the Lake Tuakitoto Action Plan.

Activity	Previously endorsed delivery date	Proposed new delivery date
Work collaboratively with mana whenua, stakeholders, and community to develop final Implementation Plan	May 2024	December 2024
ORC to design and pilot Onsite Wastewater Management System education programme in catchment	June 2024	April 2025
Scope work to improve access and visitation	June 2024	June 2025
Discussions with ORC natural hazards and engineering to identify any risks of below activities	May 2024	October 2024 and as new sites are proposed
Engage/collaborate with catchment groups, landowners and community groups to fence, plant and maintain priority areas	June 2025	June 2026
Report on Fish Passage study of Lake Tuakitoto	June 2024	June 2025
Hydrological assessment	June 2024	June 2025

[19] In June 2024 ORC provided direct funding from the budget allocated to deliver this project for a total of $110,000 to Otago South River Care Group to enable the group to deliver fencing and planting works to improve water quality of the lake. The catchment group has reported that the planting project is currently being socialised with farmers in the area, and a planting day has been organised with catchment group members for 2nd

November at the lake car park area. Further progress will be made following lambing and calving in the area and the majority of the planting is scheduled for 2025.

Lake Hayes/Waiwhakaata

[20] The Lake Hayes restoration project aims to improve water quality within Lake Hayes and reduce the risk of flooding along the perimeter of the lake. Currently there are flooding impacts to the existing recreational trail which affects public access, negatively impacts on the Crested Grebe habitat, increases runoff of nutrients from flooded land and impacts adversely on native planting which has been established for local biodiversity restoration along the shores of Lake Hayes.

[21] An update of progress to May 2024 was presented to the Environmental Implementation Committee on 8 May 2024. Since this time the Waiwhakaata /Lake Hayes Strategy Group is continuing to support the development of a refreshed strategy. The strategy refresh is well underway with completion of this document due in December 2024.

[22] The Mill Creek (Arrow River water) augmentation works are nearing completion. The physical pipe infrastructure is all in is all in place and sediment that has built up over time around the structure which discharges to Mill Creek is to be removed prior to commissioning the pipe. This is to ensure that sediment is not dislodged and discharged downstream when it is first turned on. The sediment removal requires a consent which is in place and we are collaborating with Mana Tahuna and Millbrook to align sediment removal from existing ponds and utilising the same contractor whilst on site. This joined up approach will support water quality enhancements in the lake and catchment as we efficiently utilise resources. The sediment removal work is scheduled for late October/early November 2024.

[23] ORC is establishing a commissioning working group to go through the risks associated with the commissioning process for augmentation and ensure co-ordinated involvement from all stakeholders. The working group will include representatives from the following groups: ORC, Arrow Irrigation Company (AIC), Friends of Lake Hayes (FOLH), Mana Whenua, project consultants (Egis, Mitchell Daysh) and Base Contracting. Millbrook Resort representatives will also be invited.

[24] The Waiwhakaata Strategy Group continues to provide an effective mechanism to bring all parties together to discuss issues of mutual interest and to act as a liaison point between mana whenua, the community and government agencies. It has facilitated better communication and enabled ORC to quickly engage the views of partners and key stakeholders to ensure acceptable progress is made to deliver the Lake Haye restoration project.

Toitū Te Hakapupu

[25] The $4.0m, Ministry for the Environment funded, Toitū Te Hakapupu/Pleasant River Catchment Restoration Project, with the objective of improving/protecting water quality in partnership with Kāti Huirapa Rūnaka ki Puketeraki, is progressing. The Partnership Group for this project is also represented by the East Otago Catchment Group.

[26] The rivers and estuary of Te Hakapupu have had excess sedimentation and nutrients deposited throughout the catchment which impacts on ecosystem habitat and health, cultural values, as well as reducing recreation and amenity values.

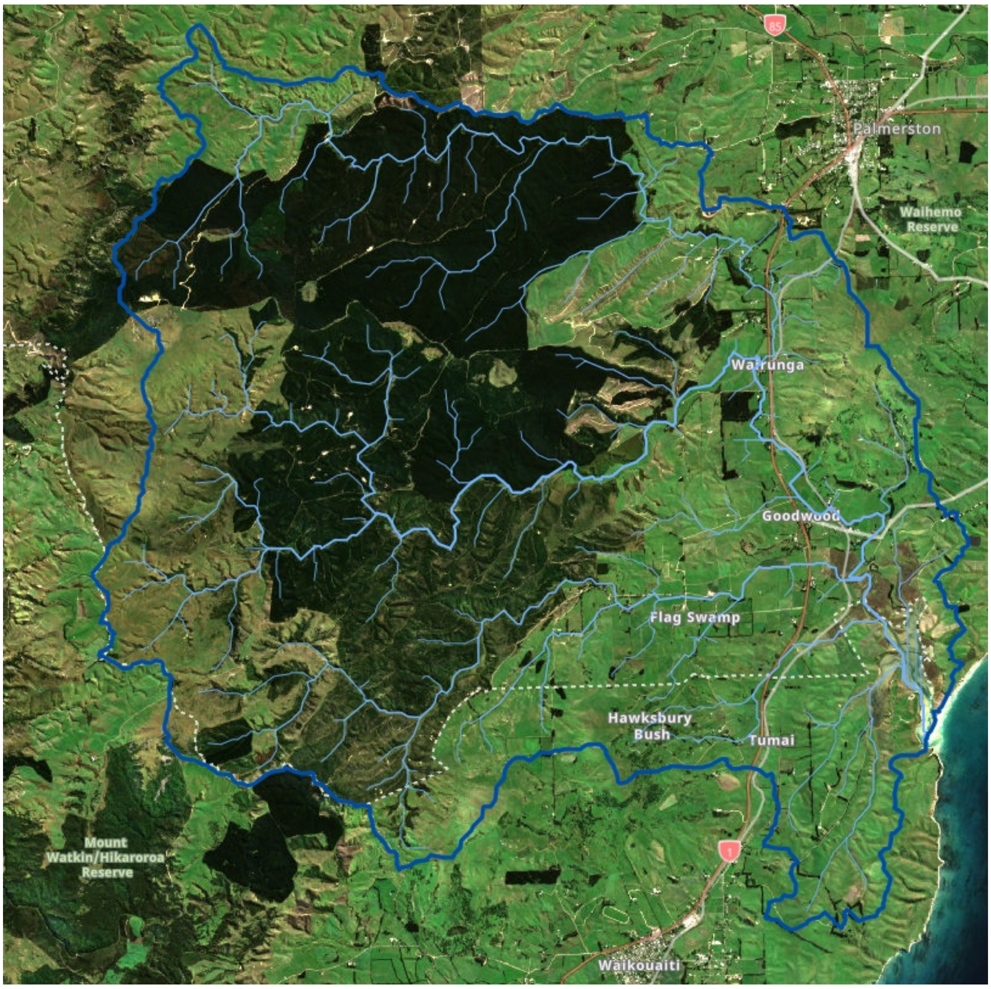

Figure 4: Satellite showing catchment boundary (dark blue) and the three main waterways (light blue) leading into the estuary, Te Hakapupu (Pleasant River), Te Owhakaoho (Trotter) and Watkin.

[27] The purpose of the Toitū Te Hakapupu project is to implement effective interventions to reduce sediment and nutrients and better safeguard the water resources from *ki uta ki tai* (mountains to the sea). The ultimate receiving environment includes the proposed Te Umu Koau marine reserve and supporting good quality water entering this is important.

[28] The project has three strands:

a) Rural Interventions Programme – this involves fencing waterways, planting 75,000 indigenous plants (and maintenance of these plants), supporting and implementing good management practices across water quality, biodiversity and biosecurity, restoration/remediation of degraded wetlands and identification and rectification of fish passage barriers.

b) Forestry Interventions Programme – this involves engaging with, and supporting, landowners and forestry companies to develop a Forestry Action Plan and implement practices to minimise impacts on stream health and biodiversity, explore different approaches to prioritise land stewardship and best practices for sustainable harvesting and beyond regulation advice and action.

c) Community Engagement, Education and Action – this involves the development and implementation of a catchment action plan, and the provision of information and opportunity for community to shape and influence project delivery.

[29] Since the last update the project has achieved the following:

a) The Catchment Action Plan is now in final draft form and was shared with the community at a hui on 23 October, 2024 for input and feedback. Key values for the catchment have been identified based on workshops and discussions with the community and representatives of Kāti Huirapa ki Puketeraki. Strategies and actions have been identified to support/enhance these values, many of which will be supported by the Toitū Te Hakapupu project.

b) Environmental Baselines have been set and results show that Te Hakapupu/Pleasant River estuary has similar characteristics to other estuarine systems in Eastern Otago with similar fish species and numbers, including four considered to be mahika kai; kahawai, sand flounder, skate and yellow eyed mullet.

c) Water quality monitoring has been completed for the second year. Results so far indicate that turbidity (the measure of sediment in the river) exceeds the recommended threshold for ecosystem health. Detailed analysis of the metrics will be undertaken once sufficient samples have been taken.

d) Sediment hot spots have been identified using NIWA sediment source tracking, risk mapping and erosion mapping. Ground truthing has confirmed a number of hot spot areas. These include stream banks, areas of active erosion and areas of mass movement. Sediment mitigation actions and planning are underway, with fencing and planting river margins and wetlands, sediment traps and erosion planting proposed for priority sites.

e) Riparian fencing completed or currently underway is 29.5 km. Wetland fencing to protect Te Hakapupu regionally significant wetland is underway with approximately 7.9 km of fencing proposed to exclude stock.

f) A second community planting day was held in August 2024 in Goodwood. Over 50 people, including families and children participated and 1200 plants were planted, despite quite wet conditions. A second schools education day which included planting, stream health study and an introduction to cultural health monitoring was also held in September.

g) Landowner engagement continues within the catchment. The project has identified 56 landowners with properties that could have water quality improvement works installed (streambank erosion, active erosion, mass movement). Of these the project team have engaged with 45 (80%) landowners. Works are either complete, underway or planned for 35 of those, and engagement is still underway. This is a 78% success rate for landowner engagement.

[30] Kāti Huirapa Rūnaka ki Puketeraki have involved up to ten rūnaka members directly working on the project at times as well as a project coordinator. Activities to date include:

a) The nursery is producing up to 40,000 plants for the project;
b) Whānau have produced a Cultural Health Monitoring Plan and are undertaking ongoing cultural health monitoring;
c) A capacity and capability plan has been completed;
d) A video story is being produced to share project achievements and highlights for the rūnaka; and
e) 20 fish passage barriers were identified in the catchment and all have been assessed for fish passage for native fish species. The outcome was that seven structures are considered priority for replacement or improvement. Five of the seven are high priority for replacement or improvement and the project team are working with landowners to support rectifying these barriers.

[31] Staff will continue to provide up to date reporting to MfE. This includes quarterly reports, annual reports and a final project report.

[32] By June 2025, the project will have implemented on-the-ground mitigation activities in line with the funding deed. Further planned activities, are included in Attachment 1. By the end of the project, completed work is expected to include installing over 20km of fencing, planting over 75,000 native trees, restoring fish passage to five barriers in the catchment, and a range of other potential remediation actions – like sediment traps, erosion planting, willow removal, wetland restoration, and riparian buffers in forestry areas. This is significant work by the community.

Hill Country Erosion

[33] In June 2023, project funding was confirmed with a signed agreement between Ministry for Primary Industries (MPI) and ORC. Key objectives for the Hill Country Erosion project are:

a) Increase ORC's knowledge of hill slope erosion;
b) improve ORC's engagement with mana whenua and landowners on ways to address hill country erosion; and
c) identify and mitigate hill slope erosion in priority areas.

[34] Funding over four years for the project is detailed in Table 6.

Table 6. Hill Country Erosion project funding

MPI Funding	$429,537
ORC (cash and in kind)	$599,250
Projected landowner contribution (cash and in kind)	$38,080

Total	**$1066,867**

[35] Milestones for the first financial year (2023 – 2024) have been completed with two still ongoing (Table 7). Work is progressing on the milestones for the 2024/25 financial year.

Table 7. Funding agreement milestones for the Hill Country Erosion project 2023/24

Milestone	**Date Completed**
Recruitment of a Land Management Advisor	May 2024
Planning documents prepared (Engagement Strategy, Monitoring and Evaluation Plan)	March 2024
Regional Erosion Control Strategy commenced	June 2024
Prioritisation mapping and analysis	June 2024
Stocktake/ review of existing data and mapping	Ongoing
Engagement activities in line with strategy	Ongoing

[36] The project intent is to use an evidence-based approach to determine priority hill country erosion focus areas across Otago. To inform this, a Regional Erosion Control Strategy was developed by Boffa Miskell and Prioritisation Mapping and Analysis was completed by e3Scientific in June 2024.

[37] Prioritisation mapping provided no clear region-wide overview of where priority effort should be focussed. A Hill Country Erosion Technical Advisory Group (including 9 members from across a range of ORC teams and one external advisor) has been established to provide advice on the proposed strategy and on refining mapping and prioritisation work to improve the Otago lens on priority areas.

[38] The Dunedin coastal transport corridor (Karitane to Scroggs Hill) (Figure 6) has been identified as a high-risk area for hill country erosion (*Hill Country Erosion Mapping and Prioritisation Report*, e3Scientific) and *Otago Regional Erosion Control Strategy*, Boffa Miskell). Project implementation will initially focus on project pilot sites within this zone. It is intended that these pilot projects will be the catalyst for development of workshops and wider advocacy opportunities that can be rolled out across the Otago region (2025 – 2027) with at least one project/ demonstration site established within each of Otago's Freshwater Management Units.

Figure 13. Kilmog and coastal predominantly focused on areas with recorded activity. Recent erosion was identified in landslide areas with no recorded activity. Site ID matches the ID in Table 8.

Hill Country Erosion Mapping and Prioritisation Report
Document ID: 24002

Figure 6: Dunedin coastal transport corridor showing high risk erosion sites.

[39] With support from Kati Huirapa Rūnaka ki Puketeraki and Aukaha, ORC are working with trustees on a block of Māori title land near Seacliff, as a pilot project site. Trustees and landowners are invested in restoring their whenua and are advising and informing the approach to erosion control on their land.

[40] A project information page has been set up on the ORC website and will be updated regularly as more information becomes available.

[41] Staff will continue to provide up to date reporting to MPI. This includes six-monthly reports and a final project report.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[42] ORC's strategic directions commit ORC to delivering integrated environmental management, engaging communities and collaborating to deliver, and this work is consistent with those commitments. Where water quality is degrading, ORC is required to implement an action plan to address the degradation. This work is an early example of such a plan.

Financial Considerations

[43] The budgets for these projects have been accounted for in the Long-Term Plan 2021 – 2031 and in the Long-Term Plan 2024-2034. All projects remain on track with their budgets, with regular reporting provided to MFE or MPI where funding has been provided.

Significance and Engagement Considerations

[44] This update is consistent with the Council's Significance and Engagement Policy.

Legislative and Risk Considerations

[45] This paper does not trigger legislative or risk considerations.

Climate Change Considerations

[46] Lake Tuakitoto plays a significant role as a catchment ponding area during flood events in the Lower Clutha Flood Control and Drainage Scheme.

Communications Considerations

[47] Communications around the projects is ongoing and the Environmental Implementation staff will work with the Communications team.

NEXT STEPS

[48] Work to deliver on these projects and programmes will continue.

ATTACHMENTS

1. Attachment 1 [**9.1.1** - 1 page]

Attachment 1

Table : Toitū Te Hakapupu – planned activity		
Activity	**Description**	**Planned time**
Community workshops	to deliver community science and foster connections between landowners, forestry industry and our iwi partners and promote project successes.	Fish passage workshop – EOCG led and ORC supported - early 2025
	Community science sessions – 3 or 4 to be held throughout the next year.	February 2025, April 2025
	Planting day	May 2025
Communications	Newsletter, science web page, comms about events (before and after), media release, video story	Throughout project
Planting and fencing	Will continue as the project works toward KPI targets and beyond.	Fencing ongoing. Planting April to 30 June 2025.
Sediment traps and erosion planting	For priority properties with active erosion	Erosion planting April – June 2025
Fish passage barriers	5 fish passage barriers to be replaced or improved to enable native fish to travel up and downstream and increase access to habitat.	Summer 2024/2025
Willow removal	Three sites have been selected as priority for removal to improve water quality and habitat.	Summer 2025
Water quality monitoring	To gain an understanding of changes in water quality over time considering seasonal change and storm events	Summer 2025
Catchment Action Plan including Forestry Action Plan	Input from Puketeraki and community and finalised as a living document.	Community meeting 23 October 2024 Finalised document February 2025

9.2. Corbicula Fluminea Update

Prepared for:	Environmental Implementation Committee
Report No.	GOV2445
Activity:	Governance Report
Author:	Sarah Irvine, Team Leader Project Delivery; Libby Caldwell, Manager Environmental Implementation
Endorsed by:	Joanna Gilroy, General Manager Environmental Delivery
Date:	7 November 2024

PURPOSE

[1] To provide an update on work undertaken in response to the notification of an incursion of exotic freshwater clam species (*Corbicula fluminea* and *Corbicula australis*) into the North Island of New Zealand Aotearoa.

EXECUTIVE SUMMARY

[2] A new-to New Zealand Aotearoa freshwater clam (*Corbicula fluminea*) was detected in the Waikato River in May 2023. In March 2024, a second species of exotic freshwater clam (*Corbicula australis*) was detected at the Lake Taupō Aqua Park. These species are considered to be highly invasive as they can spread quickly in rivers using water flows and are easily transported to new waterways via human activity. They can out-compete and displace native and taoka species, compromise water quality, clog and damage water infrastructure, such as hydroelectricity and municipal water, and impact tourism and recreational values. The potential environmental and economic impacts to Otago's lakes and rivers could be significant.

[3] Biosecurity New Zealand/ Manatū Ahu Matua (BNZ) has led the initial response to date. The aim of this response has been to ascertain the extent of the infestation, implement preliminary measures to contain infestations and prevent the spread. Following initial surveillance, there have been no detections of *Corbicula* outside of the Waikato River and Lake Taupō Aqua Park.

[4] ORC staff have implemented measures to raise awareness of the potential threat of *Corbicula* to Otago and to prevent incursion. Involvement in this work programme is part of Council's surveillance work and underscores the importance of our Marine and Freshwater biosecurity work.

RECOMMENDATION

That the Committee:

1) ***Notes** this report.*

BACKGROUND

[5] In May 2023, Biosecurity New Zealand/ Manatū Ahu Matua (BNZ) notified Regional Councils that an incursion of a new-to-New Zealand freshwater clam (*Corbicula*

fluminea) (Figure 1) had been detected in the Bob's Landing area of the Waikato River near Lake Karāpiro. Through a surveillance programme led by BNZ, including methods such as visual detection, core sampling and eDNA, infestations have since been confirmed in the Waikato River from Lake Maraetai Landing to Tuakau.

[6] In March 2024, BNZ notified Regional Councils that a second species of exotic freshwater clam (*Corbicula australis*) (Figure 1) had been detected at Lake Taupō Aqua Park in a small artificial lagoon. Surveillance to date indicates that this species is confined to the Lake Taupō Aqua Park.

Top: Corbicula australis
Bottom: Corbicula fluminea
Photos credit: Jean-Claude Stahl and Kerry Walton, Te Papa.

Figure 1. *Corbicula australis* and *Corbicula fluminea* comparison, www.mpi.govt.nz

[7] *Corbicula fluminea* is native to eastern Asia and is widely established in North and South America and Europe. *Corbicula australis* is native to Australia, where it is common and widely distributed. Both species are considered freshwater pests in New Zealand Aotearoa and are considered a significant potential threat to freshwater ecosystem health.

[8] As these species are new to New Zealand Aotearoa, there is little known about what the impacts are likely to be. However, the consequences of invasion of *C. fluminea* in other countries is well documented and provides information of the potential impact.

[9] Both species of freshwater clams can produce 400 juveniles per day and up to 70,000 juveniles per year, resulting in infestations reaching extremely high densities in optimal conditions and smothering benthic habitats with shells (Figure 2). This has given *Corbicula* a reputation of one of the most prolific freshwater invaders worldwide (Somerville et al. 2024).

Figure 2
Photo taken in France of *Corbicula fluminea* infestation taking over the benthic environment **https://inpn.mnhn.fr/espece/cd_nom/163433?lg=n**

[10] The potential impacts of these freshwater clams, if they spread to Otago includes competition with and displacement of native species like Kākahi/Freshwater Mussel (*Echyridella menziesii*) and exacerbation of water quality issues by reworking sediment and releasing nutrients (Somerville et al. 2024). These impacts present a direct threat to mahika kai (traditional food-gathering practices) and broader cultural and recreational values associated with freshwater ecosystems. *Corbicula* can clog water-based infrastructure, such as electricity generation plants, irrigation systems, and water treatment plants posing significant economic costs for water infrastructure maintenance and repair. For example, Watercare estimates that, since 2023, it has invested close to $100,000 in measures to ensure clams do not cause issues at the Waikato Water Treatment Plant (Freshwater clams response – Update #16, MPI).

[11] To date, surveillance of rivers and lakes in the Waikato and Bay of Plenty, as well as nationally, has shown no detection of *Corbicula* outside the Waikato River and Lake Taupō Aqua Park. However, these populations are considered well established (Corbicula is believed to have been present in the Waikato River for at least three years prior to detection), and there are concerns that *Corbicula* will spread throughout the country.

[12] Both species can survive a wide range of temperatures and are considered a potential threat to Otago freshwater systems (Somerville et al., 2024).

[13] BNZ have implemented legal controls to try to contain *Corbicula* and prevent spread. Both *Corbicula fluminea* and *Corbicula australis* have been given the legal status of Unwanted Organism under the Biosecurity Act 1993. This means that moving the clams, or water that may contain these clam species, is an offence under the Biosecurity Act 1993. However, most consent holders with a consent to take water from the Waikato River under the Resource Management Act (RMA) such as for irrigation, municipal water supply, or other commercial uses are still consented to do so.

[14] BNZ have also put in place two Controlled Area Notices (CANs) under the Biosecurity Act 1993. One for the Waikato River with specific rules for all wake boats (Appendix 1) and one for Te Arawa lakes with additional protections for Lake Ōkataina (Appendix 2). However, enforcement of the CANs is challenging, resource intensive and is mostly reliant on voluntary compliance.

Figure 3
Freshwater gold clam Check, Clean, Dry and Controlled Area Notice (CAN) signage at Lake Tarawera, September 2024.

[15] As part of the initial response, BNZ engaged NIWA to undertake research to provide a better understanding of the habitat and depth range that the clams occupy (Appendix 3) and the effectiveness of various control options for managing juvenile clams (Appendix 4). In addition the Cawthron Institute has published research on habitats in Aotearoa New Zealand that are suitable locations for *Corbicula fluminea* to establish (Appendix 5). This research has now been completed and it is intended that it informs potential future management efforts.

[16] In addition, BNZ established a Technical Advisory Group (TAG) to provide scientific and technical expertise and provide a foundation for decision about the management.

DISCUSSION

[17] There are numerous freshwater systems in Otago that are considered suitable for *Corbicula* colonization. A habitat suitability model indicates that most of Otago's lakes and rivers provide the temperature and nutrient conditions conducive to *Corbicula* establishment (Sommerville et al. 2024). Additionally, Otago's significant infrastructure, including irrigation systems, hydroelectric dams, and municipal water intakes, would be at risk of biofouling if *Corbicula* populations were to establish in the region.

[18] Infestations of *Corbicula fluminea* in other countries, beyond its native range, have been difficult to control and eradication has to date, not been achieved. *Corbicula* can withstand a variety of water conditions and can survive 8-10 days out of the water (maybe even longer for some fully mature clams). These species may be able to survive in the gut of fish and birds and therefore be transported and released in other locations. They can withstand different thermal tolerances with extremes of heat and cold and in areas of low oxygen (www.mpi.govt.nz).

[19] It has been determined that eradication of *Corbicula* from the Waikato River is not feasible with the current tools available. Therefore, the biosecurity response activated by BNZ has focussed on ascertaining the extent of the infestation and on containment and suppression to prevent the spread. See Appendix 6 for the TAG report.

[20] Therefore, the focus of the response is to implement a containment strategy to ensure that it does not spread from the current known locations. Strategies implemented so far, both nationally and throughout the Otago region, are detailed below, including surveillance for early detection; education and advocacy through the Check, Clean, Dry campaign and general communications; internal good biosecurity practices; and passive surveillance from the public.

Surveillance for Early Detection

[21] Early detection allows for a quick response and potential for control to undertake local eradication of populations that may not yet be established.

[22] ORC staff have proactively implemented a surveillance programme using water sampling for environmental DNA (eDNA). This eDNA technology allows for detection of genetic material of invasive species in water samples, providing an early detection system even before visual populations can be identified. To date, two eDNA surveillance rounds have been undertaken by the ORC Environmental Monitoring team. The results have not detected *Corbicula* at any of the Otago sites tested (Figure 4). BNZ have advised annual eDNA testing and another sample is scheduled for Summer 2024.

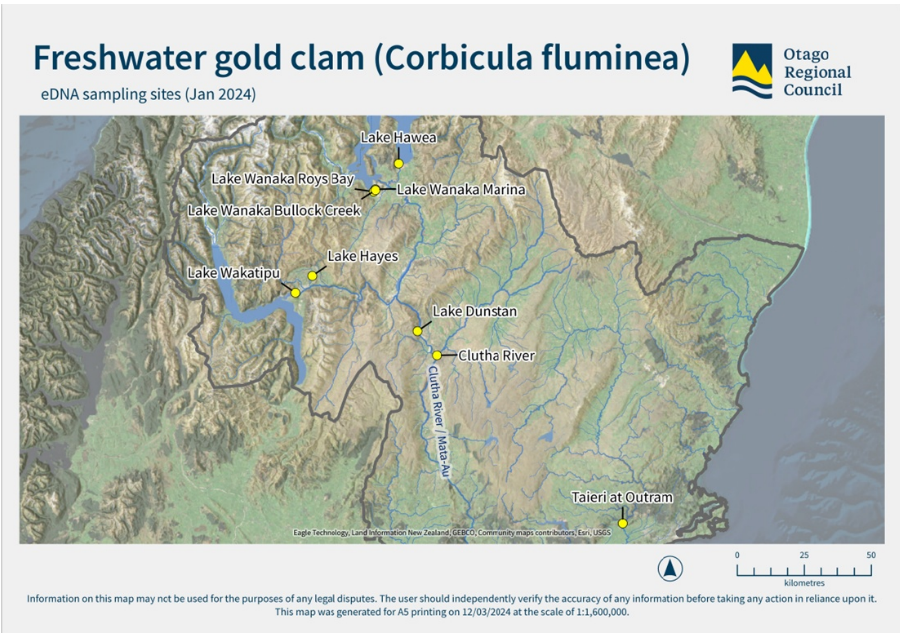

Figure 4
Locations of eDNA sampling January and April 2024. Details of species found at these locations can be viewed on the Wilderlab website (provide link).

[23] Other surveillance efforts include briefing the divers, engaged by Toitū Te Whenua, Land Information New Zealand (LINZ) to manage invasive lagarosiphon in some of Otago's high-risk lakes, to look out for *Corbicula* during underwater dives.

[24] The ORC biosecurity team implement an annual freshwater biosecurity surveillance programme for aquatic pest plants. Staff are considering how to include methods to detect *Corbicula* into regular surveillance. This will include surveys of high-risk areas such as boat ramps.

Internal Good Biosecurity Practices

[25] As part of ORC's ongoing efforts to improve regional freshwater biosecurity practices, ORC is developing an internal Standard Operating Procedure (SOP) for ORC field teams. This SOP will provide detailed guidance on decontaminating equipment using the appropriate treatments, with provisions for adjusting protocols based on the latest research. The SOP will be aligned with national biosecurity guidelines and will incorporate input from mana whenua to ensure the cultural considerations are integrated into operational practices.

Education and Advocacy: Check, Clean, Dry

[26] It has been identified that one of the most significant potential pathway risks for spread to the South Island is through recreational activities. These include boating, kayaking, and fishing and the transport of contaminated boats and fishing gear on inter-island ferries and flights.

[27] The current method being used to address this pathway is through the national Check, Clean, Dry campaign. This campaign is currently implemented nationally as an education and advocacy programme to prevent the spread of didymo and invasive freshwater plants, such as lagarosiphon, hornwort, and Egeria. This season the campaign will be joined up with the boating safety campaign run by the Harbourmaster Team, which will provide enhanced opportunities to talk to water users about biosecurity risks such as the clams.

[28] As *Corbicula* can survive out of the water for significant periods of time (8-10 days), and the regular Check, Clean, Dry processes using dishwashing detergent are ineffective on *Corbicula,* an additional Check, Clean, Dry process has been developed for *Corbicula.* This process differs to the previous standard process that has been required for didymo and aquatic pest plants (Appendix 7). The drying time requirements and introducing hot water and freezing options for absorbent materials are key changes to the process (Appendix 7).

[29] At this stage, due to *Corbicula* not yet being detected in the South Island, and the risk of impacting the current Check, Clean, Dry programme, ORC has, in collaboration with other South Island Regional Councils, decided to maintain the standard Check, Clean, Dry messaging. This method is not effective against *Corbicula* but is consistent with the signage throughout Otago, it is considered more practical and achievable for the public and therefore is more likely to be undertaken to prevent the spread of other high-risk threats to Otago. At present only inter-regional recreational events in the South Island

are recommended to follow the more comprehensive *Corbicula* Check, Clean, Dry message. This approach may change if clams are found elsewhere in the North Island.

[30] ORC can work to raise awareness of the threat of *Corbicula* and provide appropriate messaging through the annual Check, Clean, Dry campaign. However, there is no regulation to enforce this campaign, nor the capability or capacity to be at all potential sites at all times to monitor recreational users. In other countries, the use of public messaging, similar to Check, Clean, Dry appears to have had limited impact in slowing the spread of *Corbicula* (Somerville et al. 2024). BNZ provide funding to engage Check, Clean, Dry ambassadors and collateral for the national Check, Clean, Dry campaign.

Education and Advocacy: General Comms and Passive Surveillance

[31] To increase awareness of the risk of *Corbicula* to Otago, ORC has implemented a Communications Plan. To date, this has included a media release, multiple social media posts, articles in On Stream and Te Mātāpuna/The Source, and clams set in resin blocks that can be used to show people what the clams look like (Figure 5).

[32] In addition, ORC has developed a page for *Corbicula* on the Pest Hub in the aquatic pests space and the Check, Clean, Dry ambassadors will raise awareness by engaging with the public over summer and distributing information sheets at boat ramps and events (Appendix 8).

[33] These communications support and encourage passive surveillance by the public and recreational water users and direct people to report any sightings of *Corbicula.* For additional updates or to report a sighting, people can visit the page developed on Council's website.

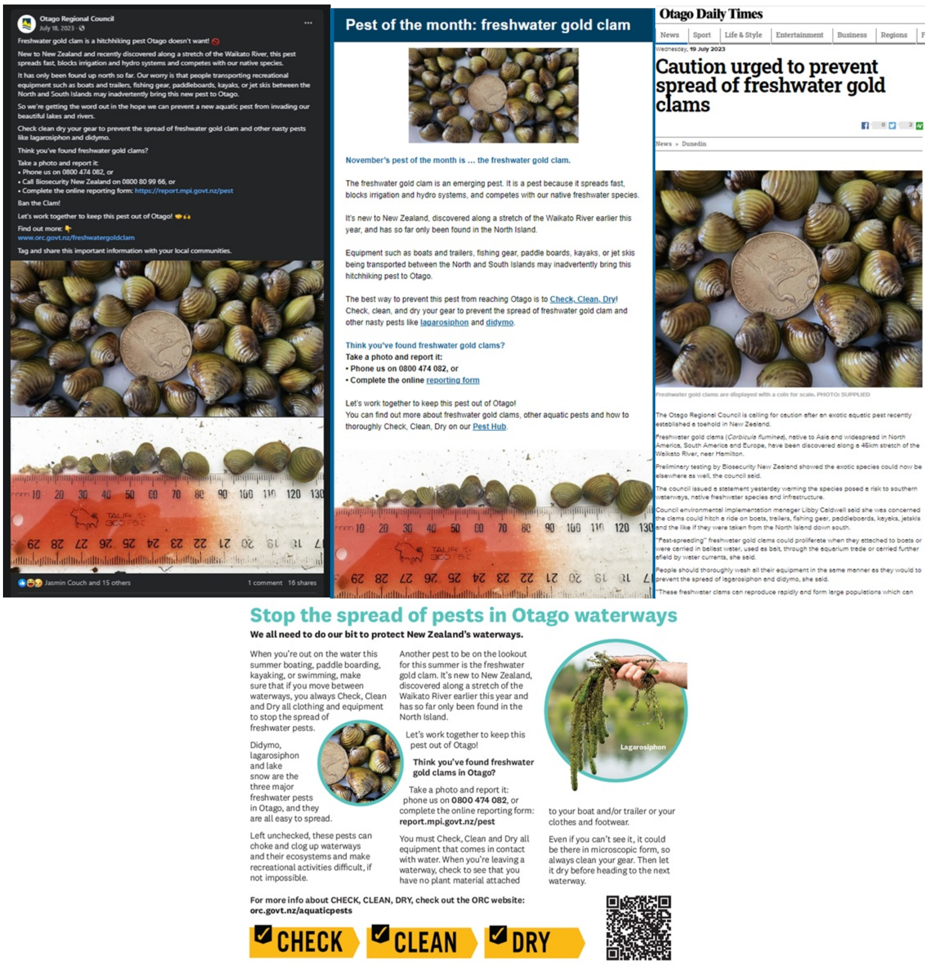

Figure 5. Examples of ORC media and social media releases to raise awareness of *Corbicula* in Otago.

[34] Councillors, in their role as Governors may wish to consider supporting efforts from BNZ and signalling the importance of efforts to control the clams and prevent them from spreading to the South Island. This could take the form of writing to the Minister for Biosecurity to support the work undertaken by BNZ and advocate for continued funding efforts to halt the spread of the clam.

The Cook Strait – A Defensible Boundary

[35] To support additional interventions and prevent pathway transport, ORC staff, along with other South Island Regional and Unitary Councils and the Department of Conservation/ Te Papa Atawhai, have raised with BNZ the requirement to implement interventions at the Wellington Ferry Terminal. This is due to its role in transporting thousands of vehicles and vessels annually between regions. Implementing measures, such as mandatory vehicle and vessel checks, hot water cleaning stations, and clean vessel passes at the ferry terminal would ensure decontamination takes place and reduces the possibility of *Corbicula* being inadvertently transported to the South Island. This option is being considered by BNZ.

Long-term Management

[36] It is considered that the initial response phase is now over and there will be a move into long-term management to contain the clams to current locations and prevent the

spread. The Manager Environmental Implementation has contributed to a national working group as a representative for Te Uru Kahika (brand name) on behalf of the South Island Councils working alongside BNZ, Department of Conservation and Waikato Regional Council staff as part of looking at long-term management options. This has contributed to a draft collaborative management plan that has been developed to direct activity through to spring 2025 and set a platform for long-term action and collaboration. This plan is currently being finalised with a broader group of mana whenua and stakeholders who have been involved in the planning workshops, and in the response.

[37] In addition, ORC staff have proposed the establishment of a South Island *Corbicula* Working Group in collaboration with partners and stakeholders, such as mana whenua, BNZ, Regional Councils, Territorial Authorities, and industry to coordinate regional responses to the potential threat of an incursion. The aim of establishing this group would be to align biosecurity efforts by coordinating surveillance, containment, and control measures across South Island regions, ensuring consistency and resource sharing to integrate regional strategies into a cohesive South Island response. This group could also address funding models for critical pathway management, for example a cost-sharing approach that involves central government, regional councils, and key private stakeholders, such as hydroelectric dam operators, tourism agencies, and water infrastructure managers.

[38] In September 2024, NIWA was granted $10.2 million from the MBIE Endeavour Fund to undertake research to support New Zealand Aotearoa's response to the invasion, incorporating mātauraka and western science knowledge systems to stop the spread of *Corbicula* and safeguard taoka. Over the next 5 years, NIWA will work to improve understanding of the clams and develop tools and approaches to manage the clams and mitigate their impacts. The knowledge gained from this research will be shared with the sector to incorporate into the response.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[39] ORC's Strategic Directions commit ORC to improving the social, cultural, economic, and environmental wellbeing of Otago. This is being protected through the prevention of incursion into the Otago region. In addition, this work provides advocacy, education and collaboration to support improved environmental management and is essential to predicting and addressing emerging environmental issues before they arise. The involvement of mana whenua in the management of *Corbicula* is essential to ensuring that Te Tiriti o Waitangi obligations are upheld and that biosecurity strategies align with Māori environmental perspectives.

Financial Considerations

[40] Budget will need to be allocated for actions when a long-term management plan is finalised. It is currently envisaged that this will fit within existing budgets. If it cannot, further information will be provided to Council to seek further funding.

Significance and Engagement Considerations

[41] This update is consistent with the Council's Significance and Engagement policy.

Legislative and Risk Considerations

[42] This paper does not trigger legislative or risk considerations.

Climate Change Considerations

[43] No direct considerations related to climate change.

Communications Considerations

[44] Communications is ongoing and the Environmental Implementation team will work with the Communications team.

NEXT STEPS

[45] Continue to be involved with the development and contribute to the finalisation of the draft collaborative management plan and subsequent implementation of this where applicable.

[46] Continue to work with Councils from across the South Island and coordinate biosecurity efforts to ensure that the *Corbicula* response is aligned.

[47] Continue to advocate to BNZ for the implementation of measures at the Wellington Ferry Terminal.

[48] Consider funding models for implementation of additional measures.

References:

Somerville, R., MacNeil, C., & Lee, F. (2024). Habitat suitability of Aotearoa New Zealand for the recently invaded gold clam (*Corbicula fluminea*). *New Zealand Journal of Marine and Freshwater Research*, 1–18. https://doi.org/10.1080/00288330.2024.2368856 (Appendix 5)

ATTACHMENTS

1. Appendix 1 CAN for Waikato River [**9.2.1** - 7 pages]
2. Appendix 2 CAN for Te Arawa Lakes [**9.2.2** - 7 pages]
3. Appendix 3 Corbicula supression trial [**9.2.3** - 60 pages]
4. Appendix 4 Treatment trials for killing juvenile [**9.2.4** - 29 pages]
5. Appendix 5 Habitat suitability [**9.2.5** - 19 pages]
6. Appendix 6 TAG Biosecurity Response [**9.2.6** - 36 pages]
7. Appendix 7 Check Clean Dry_ Processes [**9.2.7** - 2 pages]
8. Appendix 8_ Information Sheet Corbicula [**9.2.8** - 2 pages]

Biosecurity New Zealand
Tiakitanga Pūtaiao Aotearoa

Corbicula fluminea Controlled Area Notice

This notice is given under section 131 of the Biosecurity Act 1993 (the **Act**) by a Deputy Chief Technical Officer of the Ministry for Primary Industries.

CORBICULA FLUMINEA **– CONTROLLED AREA AND MOVEMENT CONTROLS**

1. Commencement

(1) This notice comes into force at 11:59 pm on 24 November 2023.

(2) This notice remains in force until a notice of revocation is issued by a Chief Technical Officer.

2. Purpose

(1) The purpose of this notice is to declare the part of the Waikato River from the Whakamaru Dam to the outflow at Port Waikato to be a controlled area, establish movement controls, and specify treatments and procedures, to prevent *Corbicula fluminea* from spreading outside of the controlled area.

3. *Corbicula fluminea* is an unwanted organism

(1) *Corbicula fluminea* is an unwanted organism under the Act.

4. Interpretation

(1) In this notice, unless context otherwise requires:

Act means the Biosecurity Act 1993.

Check, Clean, Dry means the procedure set out in Schedule 2 of this notice.

Controlled area means the area declared to be a controlled area under this notice.

Craft has the meaning given to that term by section 2(1) of the Act.

Recreational craft means any craft (other than wake boats) that is not operated as part of a business undertaking for commercial gain.

Waikato River means the main trunk of the Waikato River from the outlet from Lake Taupō to the outflow at Port Waikato, including all lakes along the river system.

Wake boat means any craft with an internal tank or bladder that cannot be completely drained (and dried) or cleaned.

5. Controlled area declaration

(1) I declare that the part of the Waikato River from the Whakamaru Dam to the outflow at Port Waikato to be a controlled area in respect of *Corbicula fluminea* under s 131(2) of the

Biosecurity New Zealand
Tiakitanga Pūtaiao Aotearoa

Act (the **controlled area**).

(2) The controlled area is identified in the map in Schedule 1 of this notice.

6. Notice of controls relating to the movement of recreational craft out of the controlled area

(1) If a recreational craft has been used in or on the controlled area at any time from 11:59 pm on 24 November 2023 onwards, no person may move that craft into any freshwater environment (such as a lake, river, or stream) or any brackish water (such as an estuary) that is outside of the controlled area unless:

a. The person undertakes the relevant Check, Clean, Dry process for that craft before moving it from the controlled area to another freshwater environment or brackish water.

7. Notice of controls relating to the movement of wake boats out of the controlled area

(1) If a wake boat has been used in or on the controlled area at any time from 11:59 pm on 24 November 2023 onwards, no person may move that craft into any freshwater environment (such as a lake, river, or stream) or any brackish water (such as an estuary) that is outside of the controlled area.

8. Notice of controls relating to the movement of fishing equipment, other equipment used to gather kai, and recreational equipment out of the controlled area

(1) If fishing equipment or other equipment used to gather kai (such as fishing rods, waders, and nets) has been used in or on the controlled area at any time from 11:59 pm on 24 November 2023 onwards, no person may move that equipment into any freshwater environment (such as a lake, river, or stream) or any brackish water (such as an estuary) that is outside of the controlled area unless:

a. The person undertakes the relevant Check, Clean, Dry process for that equipment before moving it from the controlled area to another freshwater environment or brackish water.

(2) If recreational equipment (such as water skis, wakeboards, and inflatable pool toys) has been used in or on the controlled area at any time from 11:59 pm on 24 November 2023 onwards, no person may move that equipment into any freshwater environment (such as a lake, river, or stream) or any brackish water (such as an estuary) that is outside of the controlled area unless:

b. The person undertakes the relevant Check, Clean, Dry process for that equipment before moving it from the controlled area to another freshwater environment or brackish water.

Biosecurity New Zealand
Tiakitanga Pūtaiao Aotearoa

Signed at Wellington this 22/11/2023.

John Walsh
Chief Technical Officer
Ministry for Primary Industries

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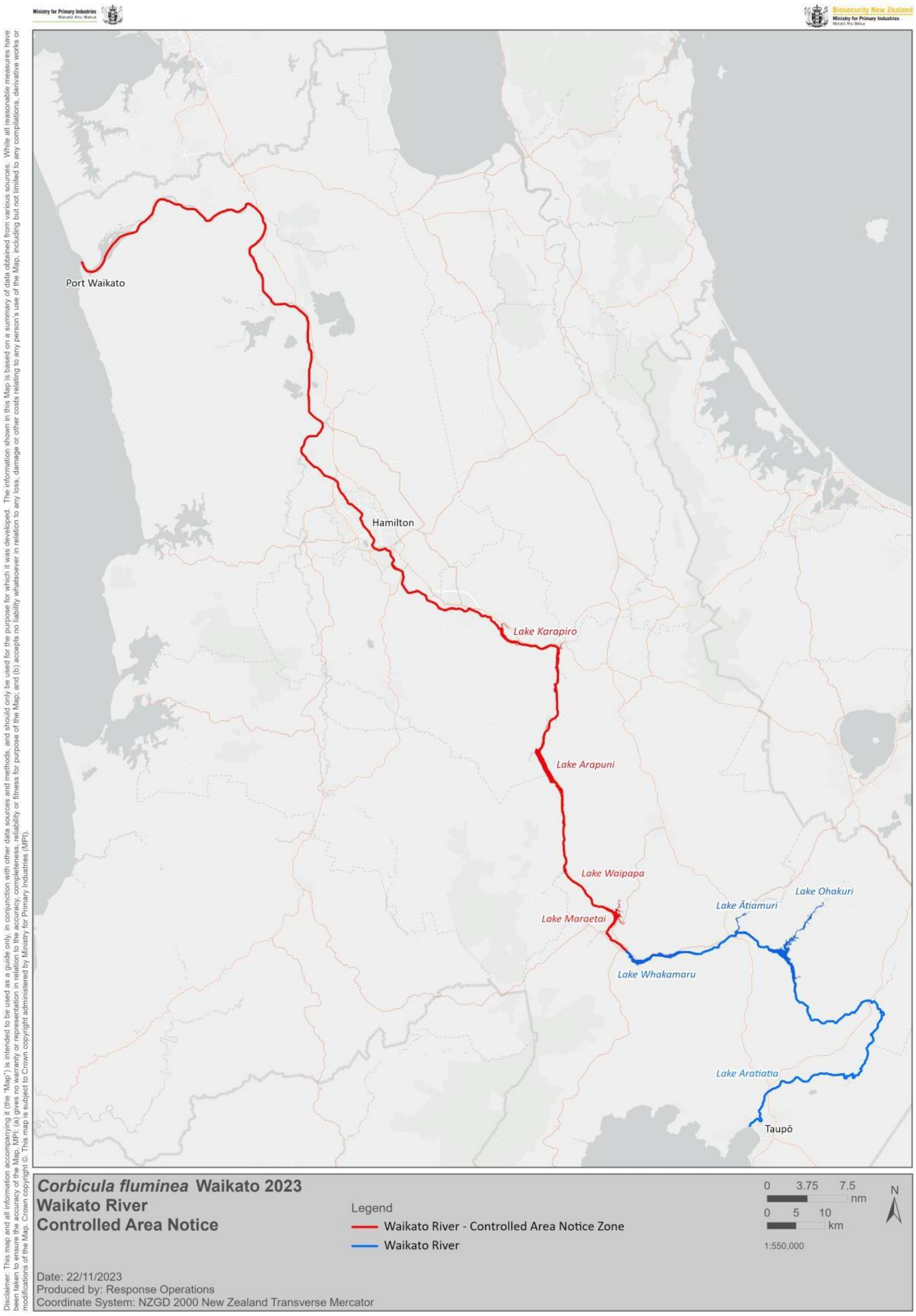
Tiakitanga Pūtaiao Aotearoa

SCHEDULE 1 - MAP OF THE CONTROLLED AREA



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SCHEDULE 2 – CHECK, CLEAN, DRY procedures for *Corbicula fluminea*

Note – procedures to manage human spread of *Corbicula fluminea* will also manage other freshwater pest species.

Check, Clean, Dry

Before moving:

- From the controlled area to into any freshwater environment (such as a lake, river, or stream) or any brackish water (such as an estuary) that is outside of the controlled area;

You must:

Check

- Remove any visible matter, including any clams you can see, along with plant material or mud. Drain all river or lake water.

Clean

- Washdown your gear, vehicle, watercraft, and trailer that has been in contact with river or lake water with tap-water onto grass, beside the waterway or at home and not into a stormwater drain system. This will remove any remaining invisible material.
- For absorbent surfaces and materials that have been in contact with river or lake water (including carpet on trailers) use an appropriate treatment in the Treatment options tables below.
- Treat residual water that always occurs when on-board ballast bladders or tanks have been pumped.

Dry

- Allow gear to dry to touch, inside and out, then leave it to dry for at least 48 hours (2 days) before using again.
- Dry areas inside the watercraft where water has pooled, for example with an old towel, and then leave the craft to dry for at least 48 hours (2 days). The hull of a watercraft will dry when towed.

Treatment options for absorbent material

Type of treatment	**Method**
Hot water	Above 60°C for at least 1 minute, or Between 50–54°C (hot household tap-water) for at least 5 minutes, or Above 45°C for at least 20 minutes.
Freeze	Until solid (that is, freeze overnight).

Other treatment options

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Type of treatment	Method
Bleach	Mix household bleach in a 10% (1 in 10) ratio with water and immerse for 1 hour.
Isopropyl alcohol	70% isopropyl alcohol, taking care as it is toxic and flammable, and there are requirements around storage and transport of isopropyl alcohol.

Note: The 'Check, Clean, Dry' advice may be adjusted as further technical information becomes available or the need arises. Refer to the manufacturer's instructions for gear and any commercial treatments.

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SCHEDULE 3 – INFORMATION ABOUT HOW TO APPLY FOR A PERMIT TO UNDERTAKE ACTIVITIES THAT ARE OTHERWISE PROHIBITED BY THIS NOTICE

This information section is not part of the notice but is intended to provide further detail about when a permit may be granted and how to apply for a permit to carry out activities that are prohibited by the notice.

MPI may permit activities that are prohibited by this notice

In accordance with section 134(1)(b) of the Act, an inspector or authorised person may permit a person to carry out an activity that would otherwise be prohibited by this notice.

Permits will be considered on a case-by-case basis and will be subject to any conditions and directions under section 122 of the Act that are necessary to manage the biosecurity risk of the proposed activity.

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Corbicula fluminea Controlled Area Notice

This notice is given under section 131 of the Biosecurity Act 1993 (the Act) by a Deputy Chief Technical Officer of the Ministry for Primary Industries.

Corbicula fluminea – Controlled Area and Movement Controls

1. Commencement

   (1) This notice comes into force at 12:00pm on 10 November 2023.

   (2) This notice remains in force until a notice of revocation is issued by a Chief Technical Officer or Deputy Chief Technical Officer.

2. Purpose

   (1) The purpose of this notice is to declare areas to be controlled areas, establish movement controls, and specify treatments and procedures, to protect the areas from an incursion of Corbicula fluminea.

3. Corbicula fluminea is an unwanted organism

   (1) Corbicula fluminea is an unwanted organism under the Act.

4. Interpretation

   (1) In this notice, unless context otherwise requires:

   Act means the Biosecurity Act 1993.

   Craft has the meaning given to that term by section 2(1) of the Act.

   Waikato River means the main trunk of the Waikato River from the outlet from Lake Taupō to the outflow at Port Waikato, including all lakes along the river system.

5. Controlled area declaration

   (1) I declare that the Te Arawa Lakes identified in the map in Schedule 1 are controlled areas in respect of Corbicula fluminea under s 131(2) of the Act (the controlled areas).

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Tiakitanga Pūtaiao Aotearoa

6. Notice of controls relating to the movement of craft or fishing equipment into any of the Te Arawa Lakes (excluding Lake Ōkataina)

(1) If a craft (such as a boat) has been used in or on any part of the Waikato River in the past 30 days, no person may move that craft into any of the controlled areas (excluding Lake Ōkataina) unless:

a. The craft has been cleaned at The Wash Place located at 338 Te Ngae Road, Rotorua and identified in the map in Schedule 1 (The Wash Place) in accordance with the cleaning requirements that are that are set out in Schedule 3 of this notice and are also displayed within each wash bay at The Wash Place; and

b. After washing the craft at The Wash Place, the person has:

i. Scanned the QR Code displayed within each wash bay at The Wash Place using a mobile device and filled out the online form that opens on their mobile device; or

ii. Taken a video on a mobile device showing that they washed their craft at The Wash Place.

(2) If fishing equipment or other equipment used to gather kai (such as fishing rods, waders, and nets) has been used in or on any part of the Waikato River in the past 30 days, no person may move that equipment into any of the controlled areas (excluding Lake Ōkataina) unless it has been cleaned and dried first.

(3) A person who complies with clause 6(2)(b) above must retain a copy of the completed online form or video for at least 30 days after they washed their craft at The Wash Place.

7. Notice of controls relating to the movement of craft or fishing equipment into Lake Ōkataina

(1) Lake Ōkataina is one of the controlled areas under this notice.

(2) No person may move any craft (such as boats) into Lake Ōkataina unless:

a. The craft has been cleaned at The Wash Place in accordance with the cleaning requirements that are set out in Schedule 3 of this notice and are also displayed within each wash bay at The Wash Place; and

b. After washing the craft at The Wash Place, the person has:

i. Scanned the QR Code displayed within each wash bay at The Wash Place using a mobile device with a QR Code scanner and filled out the online form that opens on their mobile device; or

ii. Taken a video on a mobile device showing that they washed their craft at The Wash Place.

(3) No person may move fishing equipment or other equipment used to gather kai (such as fishing rods, waders, and nets) into Lake Ōkataina unless it has been cleaned and dried first.

(4) A person who complies with clause 7(2)(b) above must retain a copy of the completed online form or video until their craft has entered Lake Ōkataina.

8. This notice does not affect any person’s obligations to comply with other notices and permissions issued under the Act

(1) To avoid doubt, this notice does not affect any person’s obligations to comply with relevant requirements or conditions imposed in notices or permissions issued under this Act in relation to Corbicula fluminea.

9. Revocation of previous Controlled Area Notice in relation to Corbicula fluminea

(1) This notice revokes the following notices:

a. The Corbicula fluminea Controlled Area Notice, issued on 28 September 2023 in relation to Corbicula fluminea; and

b. The amendment to the Corbicula fluminea Controlled Area Notice described in (a) above, issued on 31 October 2023.

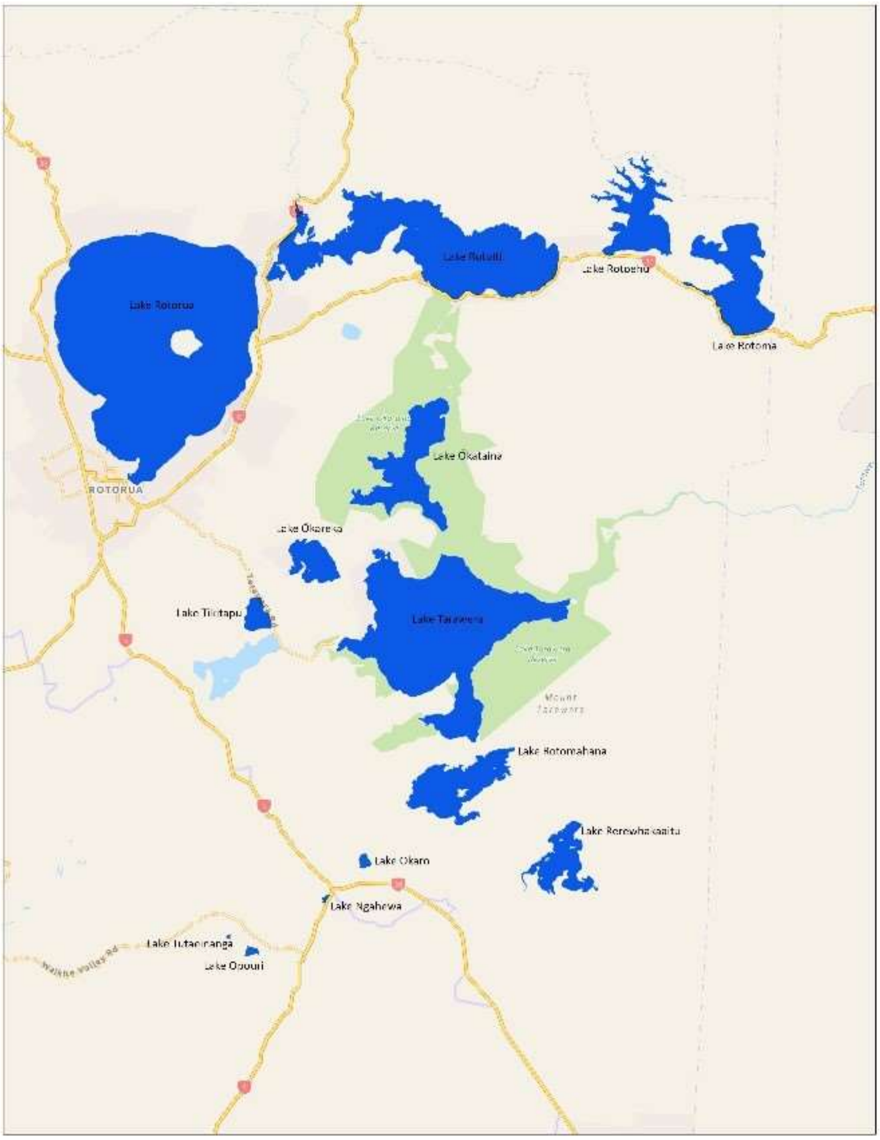
Signed at Wellington on 9 November 2023

Biosecurity New Zealand
Tiakitanga Pūtaiao Aotearoa

John Brightwell
Deputy Chief Technical Officer
Biosecurity New Zealand

Biosecurity New Zealand
Tiakitanga Pūtaiao Aotearoa

Schedule 1 - Map of Controlled Area



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Biosecurity New Zealand
Tiakitanga Pūtaiao Aotearoa

Schedule 2 – Information about how to apply for a permit to undertake activities that are otherwise prohibited by this notice

This information section is not part of the notice but is intended to provide further detail about when a permit may be granted and how to apply for a permit to carry out activities that are prohibited by the notice.

MPI may permit activities that are prohibited by this notice

In accordance with section 134(1)(b) of the Act, an inspector or authorised person may permit a person to carry out an activity that would otherwise be prohibited by this notice.

Permits will be considered on a case-by-case basis and will be subject to any conditions and directions under section 122 of the Act that are necessary to manage the biosecurity risk of the proposed activity.

Biosecurity New Zealand
Tiakitanga Pūtaiao Aotearoa

Schedule 3 – Instructions cleaning craft at The Wash Place

7

Biosecurity New Zealand

Tiakitanga Pūtaiao Aotearoa

Corbicula fluminea suppression trial baseline Cover sheet

The objective of this work was to gain a better understanding of the habitat and depth range that *Corbicula* occupy to potentially inform suppression trial work. Survey work was undertaken at Lake Karāpiro and Lake Maraetai.

This work identified several factors that were unexpected and very important to know in terms of planning any form of site management or control operations for *Corbicula.* Differences were found between survey sites indicating that site specific characteristics must be considered during planning.

- Depth ranges of *Corbicula* were from 1 m up to 30 m
- *Corbicula* were found in all types of sediment and slopes.
- *Corbicula* were found underneath large beds of aquatic weeds.
- Density of *Corbicula* populations was highest between 6-12 m (depending on the specific site).
- *Corbicula* were found below the substrate surface at depths up to 15 cm.
- Population structures indicated that *Corbicula* was well established, and recruiting.

Corbicula and kākahi had overlapping depth ranges, although the depth-density relationship of both species appeared to be quite different (i.e., highest density of both species was at different depths).

Alternative survey methods to detect *Corbicula* populations were investigated to provide potential options, other than diver surveys for any future work. A benthic dredge was found to work very well, especially in deeper water. This would be a good method for rapid detection sampling. But for more detailed understanding of the population, a combination of methods is ideal.

Corbicula fluminea Suppression Trial

Step One: Baseline

Prepared for the Ministry for Primary Industries

June 2024

Climate, Freshwater & Ocean Science

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Executive summary

Corbicula fluminea, commonly known as the gold clam, is an invasive bivalve originating from Southeastern Asia. It has rapidly spread across numerous freshwater ecosystems globally, including rivers, lakes, and reservoirs. Management of this species presents significant challenges due to its rapid reproduction, ability to form dense populations, and high water filtration rates, which can severely impact aquatic environments and associated infrastructure.

In May 2023, *C. fluminea* was detected for the first time in the Waikato River, with populations visible at Lake Maraetai and Lake Karaapiro. In response to the incursion, a multi-partner *C. fluminea* Suppression Trial Working Group developed operational specifications for these lakes. The primary goal of these specifications is to test and assess the effectiveness of various control methods, and to develop protocols for their rapid deployment. Before any suppression trials can begin, it is essential to have a comprehensive understanding of where and at what densities *C. fluminea* occur (i.e., in which habitats and water depths). This baseline information will inform the selection of locations for future suppression trials, as well as specific control methods.

To provide this baseline information, MPI engaged NIWA to:

> **Part A)** Undertake dive surveys to determine the presence, density and population structure of *C. fluminea* in various habitats and depths at a total of five sites in Lake Maraetai or Lake Karaapiro, and assess site suitability for Step 2 of the suppression trials. Step 2 of the suppression trials (deploying equipment for trialling control methods) is outside the scope of this current project.
>
> **Part B)** Develop and trial a range of alternate, cost effective, surveillance methods for *C. fluminea* (including methods where samples could be collected without divers).

Part A's dive surveys detected a total of 12,032 *Corbicula fluminea* and 1,286 *Echyridella menziesii* (kaakahi; native New Zealand freshwater mussel) across all five sample sites: Lake Maraetai - Boat Ramp (Site 1), and Golf Course (Site 2), Lake Karaapiro - Horahora Domain (Site 3), Moana Roa Reserve (Site 4), and Waipuke Park (Site 5). *C. fluminea* was present at all water depths from 1 metre to 15 metres and inhabited both gentle and steep sloping areas. *C. fluminea* density significantly increased with depth, peaking at 12 m. The highest densities were observed at Waipuke Park, Lake Karaapiro with 1556 clams/m² and Lake Maraetai Boat Ramp with 1294 clams/m².

Corbicula fluminea was found in fine mud, silt, sand, and gravel substrates, and under invasive macrophyte beds. Length frequency distributions indicated well-established populations at four of the five survey sites, pointing to ongoing recruitment (i.e., all size classes present – juveniles to adults). The most upstream survey site, Lake Maraetai Golf Course, had a narrower population structure, indicating more recent establishment. In contrast, kaakahi populations had the highest densities at mid-water depth, particularly around 6 m, and a size range indicating mature and recruiting populations.

Alternative sampling methods (Part B) demonstrated that high efficiency could be achieved using a non-diver method (the benthic dredge), especially at greater water depths. Using the dredge *C. fluminea* were found at depths up to 30 metres in Lake Karaapiro (Horahora Domain). The bespoke clam net provided the most efficient mid-depth sampling, but was constrained to depths suitable for divers.

For future surveys of *C. fluminea* populations it is important to select the appropriate method or combination of methods, to match the purpose of the survey.

It is recommended that:

- the bespoke clam net (diver operated) is used for quantitative population assessments to 10 cm substrate depths,
- benthic corers (diver, or non-diver) are used to understand the vertical substrate distribution of clams, and
- the benthic dredge (boat based) is used for rapid sampling across large area.

Our findings highlight the need for site-specific management strategies, as both *C. fluminea* and kaakahi presence and densities vary significantly across the different surveyed sites and by depth. The depth of *C. fluminea* provides some challenges for the design and implementation of suppression trials (Step Two). For example, anchoring benthic barriers on steep littoral slopes will likely be difficult. In addition, dense weedbeds may also pose a challenge due to their bulk. There are contractors in New Zealand with expertise in the installation of benthic barriers on a range of substrates and slopes, and with weedbeds. We recommend that MPI should consult these contractors prior to commencing Step Two.

1 Introduction

Aquatic invasive species often thrive in a wide range of environments, causing significant ecological and economic damage (Sala et al. 2000). One such species, *Corbicula fluminea* (commonly referred to as the gold clam), is an aggressive invasive freshwater bivalve native to Southeastern Asia (Sousa et al. 2008). This species has rapidly spread globally, reaching densities of tens of thousands per square metre across various freshwater ecosystems of the United States and Europe (McMahon 2002). These dense populations dominate the benthic communities they invade, significantly altering the structure and function of rivers, lakes and reservoirs (Karatayev et al. 2007, Sousa et al. 2008). The invasion of *C. fluminea* has also led to substantial economic costs by clogging critical infrastructure, including hydropower plants, irrigation systems, and water treatment facilities (Pimentel et al. 2005, Sousa et al. 2008, Rosa et al. 2011, Modesta et al. 2023).

The detrimental effects of *C. fluminea* are such that they require the development of effective and efficient biosecurity measures, able to prevent the introduction, spread and impacts of this organism from already infested areas to surrounding water bodies (Perrings et al. 2005, Minchin 2007). Internationally, the spread of *C. fluminea* has proven difficult to control, and eradication of established populations has yet to be achieved (Modesto et al. 2023).

The management of *C. fluminea* is particularly challenging due to the species' high adaptability and opportunistic exploitation of various resources and habitats. For instance, its ability to repopulate previously colonised habitats following population crashes caused by extreme conditions indicates an adaptation to unstable habitats (McMahon 2002). Additionally, key life history traits such as early maturity, high growth rate, and fecundity (Sousa et al. 2008, Kamburska et al. 2013), combined with human-mediated dispersal, have contributed to its invasive success globally.

The first documented occurrence of *C. fluminea* in New Zealand was in May 2023 at Bob’s Landing in Lake Karaapiro, a hydro-lake within the Waikato River. Subsequently, the Ministry of Primary Industries (MPI) contracted NIWA to undertake wadeable shoreline surveys at multiple sites along the Waikato River to delimit the extent of *C. fluminea* in the river. Populations of *C. fluminea* were detected upstream of Karaapiro, at Lake Maraetai and 40 km downstream of the initial detection site (Melchior et al. 2023). One year on, populations have been visually identified from Lake Maraetai to Tuakau Bridge.

In response to the incursion, the *C. fluminea* Suppression Trial Working Group[1] has developed operational specifications for *C. fluminea* control in Lake Maraetai and Lake Karaapiro (Biosecurity New Zealand 2023). The primary goal of these specifications is to test and assess the effectiveness of various control methods, and to develop protocols for their rapid deployment. Benthic matting is a preferred control strategy (Biosecurity New Zealand 2023). Before any suppression trial control work can begin, however, it is essential to have a comprehensive understanding of where *C. fluminea* occurs (i.e., in which habitats and water depths), and at what densities. This baseline information will help identify sites where suppression trials could be undertaken, as well as the specific control methods that could be implemented at these sites.

MPI engaged NIWA to provide this baseline information as Step One of the Suppression trials. Step Two of the suppression trials (deploying equipment for trialling control methods) is outside of the scope of this current project.

[1] Representatives from partner agencies and iwi

Step One of the suppression trials is a two-part study:

In **Part A):** Undertake dive surveys to determine the presence, density, and population structure of *C. fluminea* in various habitats and depths at a total of five sites in Lake Maraetai or Lake Karaapiro, and assess site suitability for Step 2 of the suppression trials. This part of the study aimed to answer the following key questions:

- Can *C. fluminea* be visually detected by divers?
- At what depths are *C. fluminea* populations located?
- What is the relationship between water depth and *C. fluminea* density?
- Which habitat types (e.g., substrate characteristics, bed slope, presence of macrophytes, wood, and rocks) are *C. fluminea* associated with?
- Are *C. fluminea* found beneath dense aquatic weed beds where there is limited water movement, and where low dissolved oxygen concentrations are likely to occur?
- How deep are *C. fluminea* found in the sediment?

In **Part B):** Develop and trial a range of alternate, cost effective, surveillance methods (including diver and non-diver methods) for *C. fluminea.* This part of the study aimed to provide technical guidance for four areas of field work:

- Develop a methodology that optimises efficiency and coverage of diver surveys
- Establish Shallow Water Survey Protocols
  - Create protocols for conducting shoreline and shallow water surveys that can be performed regularly with minimal ecological disturbance.
- Undertake Shallow- and Deep-Water Comparisons
  - Investigate whether observations of *C. fluminea* in shallow (wadeable) waters may be used as an indicator of *C. fluminea* presence in deeper environments, thereby improving the predictive capabilities of our monitoring efforts.
- Explore Alternative Diver and Non-diver Methods
  - Areas surveyed by divers where *C. fluminea* are known to be present will be assessed further, to evaluate the feasibility of using less labour-intensive methods such as:

    i) Adapted Wisconsin nets for less sampling effort.

    ii) Grab sampling techniques.

    iii) Benthic sleds for extensive area coverage.

    iv) Corer surveys for precise substrate sampling.

2 Methods

2.1 Study area

Lake Maraetai and Lake Karaapiro are part of a series of eight artificial reservoirs created for the hydro-electricity scheme along the 425 km long Waikato River on the North Island of New Zealand. Lake Maraetai, located 55 km downstream of Lake Taupō and formed by the third dam on the Waikato River power generating system in 1971, is the deepest of the hydro-lakes with a maximum water depth of 61 metres (Livingston et al. 1986). Despite its depth, the lake has a relatively small surface area of 4.1 km² and stretches to a maximum length of 7.2 km (Figure 2-1).

Lake Karaapiro, the most downstream reservoir in the series, is located 188 km downstream of Lake Taupō, which is the main source of water for the Waikato River. Formed in 1947 by the construction of the Karaapiro Dam on the Waikato River, the lake spans a surface area of approximately 8 km² with a maximum length of 11 km. It is a large, relatively deep reservoir with a mean water depth of 11 metres, and a maximum water depth of 30.5 metres (Lowe & Green, 1987).

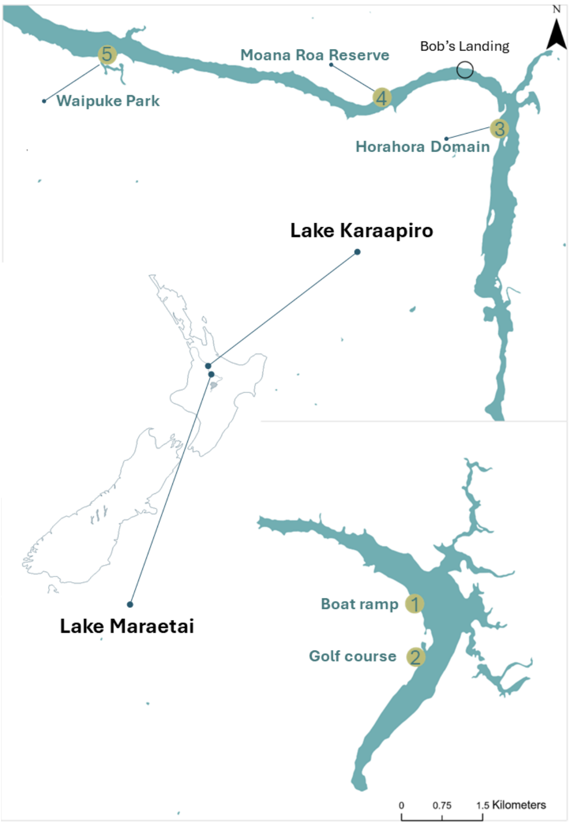

Figure 2-1: Sites selected (yellow circles) for *Corbicula fluminea* population surveys at Lake Maraetai (Sites 1-2) and Lake Karaapiro (Sites 3-5). Note that Bob's Landing (black circle) was the location of the first detection in New Zealand, and was not surveyed as part of this work.

2.1.1 Site selection

Before conducting field surveys, both MPI and NIWA worked with Raukawa and Ngāti Korokī Kahukura to select five suitable sites from Lake Maraetai and/or Lake Karaapiro (Figure 2-1). Sites were chosen based on their proximity to known populations of *C. fluminea*, representation of a variety of habitats (including water depths, and gradients), ease of accessibility, and suitability for conducting future suppression trials (Step 2).

Criteria for selecting sites for suppression trials included:

- **Presence of *C. fluminea*:** areas with recent or established populations of *C. fluminea* were prioritised to survey a range of population densities and sizes.
- **Accessibility:** Sites needed to be easily accessible for consistent monitoring and potential suppression trials in the future (Figure 2-2).
- **Habitats:** sites with a range of appropriate water depth profiles and gradients were chosen to ensure diverse habitat representation.

The five dive surveys were carried out from 20th to 27th of May 2024; two sites were chosen in Lake Maraetai (Boat Ramp, Golf course – upstream of the boat ramp) and three at Lake Karaapiro (Horahora Domain, Moana Roa Reserve, Waipuke Park; Figure 2-1,Table 2-1).

Table 2-1: Selected dive survey sites and coordinates.

Lake	Site name	Site no	Coordinates
Maraetai	Boat ramp	1	175.7809631°E -38.3656563°S
	Golf course	2	175.7809787°E -38.3736932°S
Karaapiro	Horahora Domain	3	175.6141381°E 37.9651194°S
	Moana Roa Reserve	4	175.6141381°E 37.9651194°S
	Waipuke Park	5	175.6141381°E 37.9651194°S

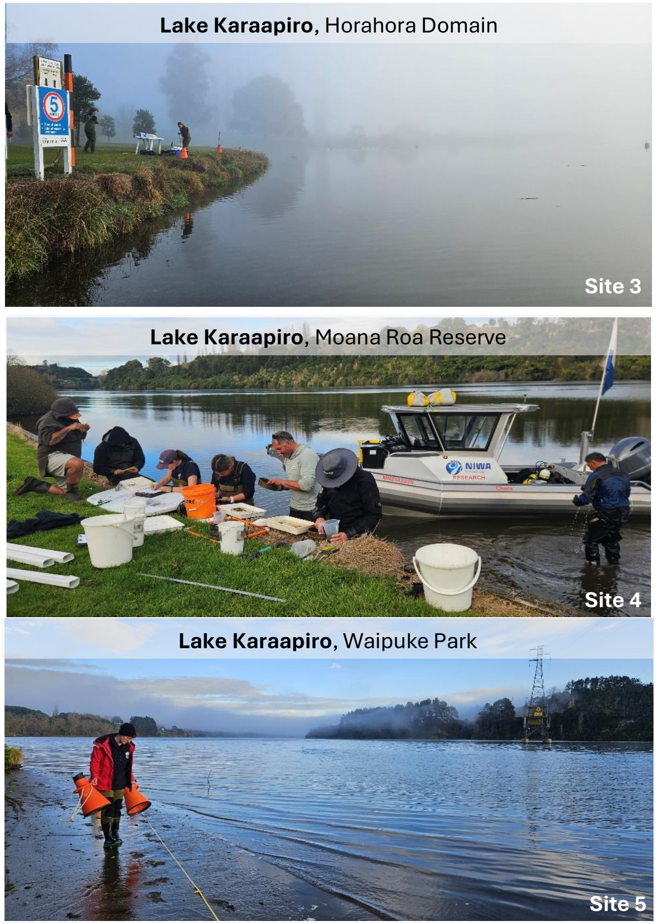

Figure 2-2: Survey sites and shore processing locations for *Corbicula fluminea*.

Lake Maraetai (Site 1. Boat Ramp, Site 2. Golf Course), and Lake Karaapiro (Site 3. Horahora Domain, Site 4. Moana Roa Reserve, Site 5. Waipuke Park).

2.2 Site characteristics

2.2.1 Visual observations of bivalves, macrophytes and substrate

Alongside quantitative sediment sampling for *C. fluminea*, divers conducted visual observations of *C. fluminea* and kaakahi at each sample site, along each profile, and at various water depths. Furthermore, habitat was described, recording macrophyte cover and type, e.g., native versus invasive weed species (Figure 2-3). Divers recorded predominant substrate type (i.e., mud, silt, sand, gravel, cobble, wood) at each sample depth. Point measurements of water temperature (°C), dissolved oxygen (mg/L, %), and pH were taken using YSI proDSS.

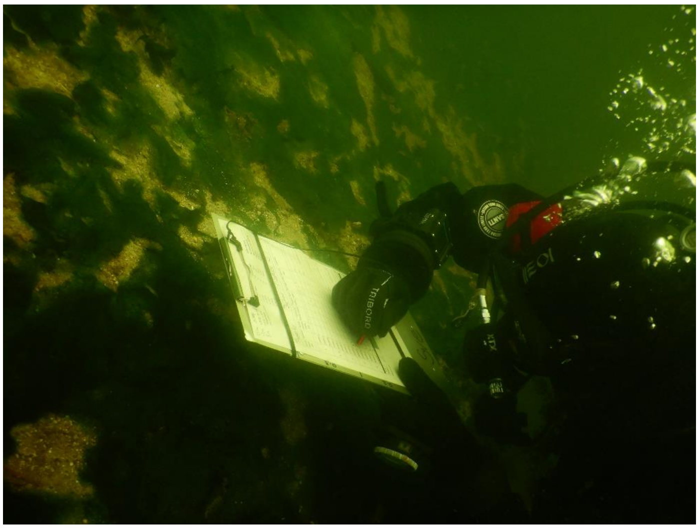

Figure 2-3: Diver recording site characteristics at Lake Maraetai Boat ramp – Site 1.

2.2.2 Hydroacoustic data collection and processing

At each survey site a single hydroacoustic trace was recorded across the three surveyed profiles from a minimum water depth of between 0.3 to 0.6 metres (constrained by navigation), to a maximum distance from shore of 122.8 to 204.4 metres (Table 2-2). The trace was recorded by a Lowrance™ depth sounder/GPS/chart plotter (model HDS 7, Navico Inc), and transducer (Active Imaging) recording at a frequency of 800 kHz. Digital data were logged as .Sl3 files.

Files were processed using Reefmaster Software Ltd (2021). The software applies algorithms to the digital data that determine water depth versus trace distance. Bottom slope was calculated from bathymetric profiles of depth measurements (±0.1 m) and trace distance (m), for all sampling aggregations.

Table 2-2: Water depth range (m) and distance (m) of hydroacoustic traces recorded at each survey site.

Lake	Site no.	Site name	Trace minimum water depth (m)	Trace maximum water depth (m)	Total Trace distance (m)	Trace distance at 15 m
Maraetai	1	Boat Ramp	0.6	15.9	122.8	122
	2	Golf course	0.3	22.2	146.7	127
Karaapiro	3	Horahora Domain	0.4	20.5	187.2	169
	4	Moana Roa Reserve	0.4	20	102.2	56
	5	Waipuke Park	0.4	30	204.4	171.6

2.3 Part A: Population survey

Dive surveys

At each of the five survey sites, divers surveyed three profiles spaced approximately 5 metres apart, with each profile perpendicular to the shoreline to collect benthic materials. The lake bed was sampled at multiple water depths along each profile, including ca. 1 metre (shoreline), 3-4 metres (shallow), 6 metres (mid-water), 9 metres (deep), 12 metres (deep), and 15 metres (deep). The shallow zone had a variable depth of 3-4 metres because the dense weed beds at some sites necessitated adjustment of survey location (and depth) to ensure diver safety. Divers remained shallower than 20 metres throughout each survey process due to health and safety requirements (Figure 2-4).

At each water depth down to 12 metres, three 0.25 by 0.25 metre quadrat samples of benthic sediment were taken down to substrate depths of 10 cm using a bespoke clam sampling net (30 % shade cloth, mesh size of 3 mm). A 0.33 cm^2 quadrat frame (or 0.575 by 0.575 cm quadrat) was placed on the lakebed to guide the handles of the bespoke clam net, ensuring a consistent sampling depth of 10 cm (see Figure 2-5). Samples derived from the three quadrats were pooled to provide a representative sample of the benthic environment at each water depth (resulting in 15 pooled quadrat samples per site, Figure 2-4, Figure 2-5).

Alongside each 0.25 by 0.25 metre quadrat sample site at each water depth, 1 core sample (40 mm diameter and 150 mm deep) was collected (resulting in 15 cores per site) (Figure 2-4). These cores were used to indicate *C. fluminea* presence in substrate deeper than that sampled by the bespoke clam net. Collection of these small core samples was particularly important in areas with dense aquatic weed beds, where the weed may have prevented use of the larger bespoke clam net (Figure 2-4).

Following the quantitative assessments, divers sampled sediment at 15 metre water depths with a single qualitative Wisconsin net sweep (0.1 m^2, net mesh 500 µm). The Wisconsin net was pulled for 1 metre, sampling the surface 10 cm of benthic substrate within each profile; this was done to determine the presence of *C. fluminea* at deeper water depths where visibility was limited (Figure 2-4).

Sample processing

Upon retrieval, all sediment samples were flushed with river water onboard a boat or onshore to prepare for subsequent processing onshore. Samples were sieved using nested sieves with mesh aperture sizes of 5 cm, 1 cm, 5 mm, and 2 mm (Figure 2-6). This method ensured that the samples were clean of finer sediments and that all *C. fluminea* longer than 2 mm could be accurately identified and counted.

Any *C. fluminea* found were counted and their shell lengths recorded to the nearest 0.1 mm using callipers. In cases where more than 50 individuals were present, a subsample of lengths (n = 50) was taken, and the remaining individuals were counted.

Similarly, all kaakahi in the benthic samples were identified and underwent the same measurement and sampling protocols. At the end of the survey, all native species were returned to the lake. *C. fluminea* were euthanised in 80 % IPA, and double bagged before being transported for disposal.

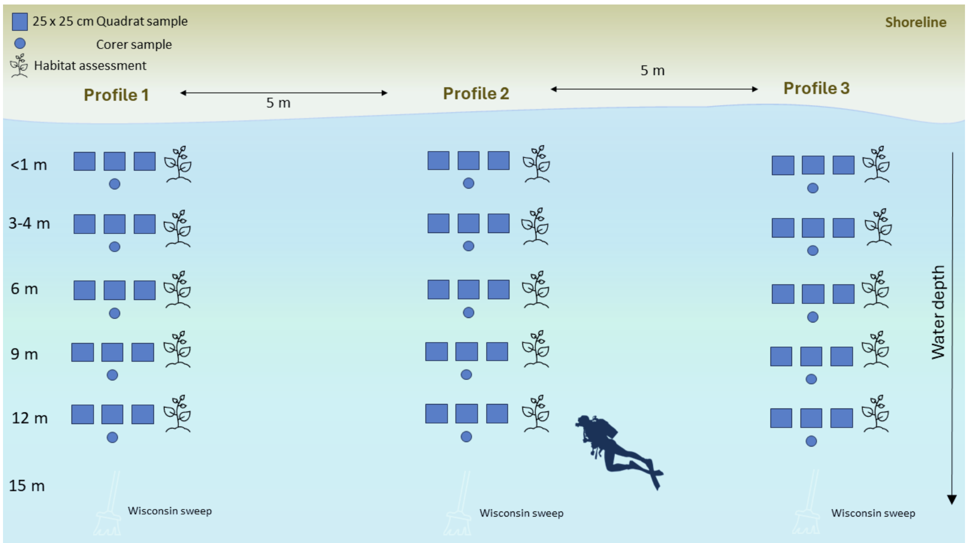

Figure 2-4: Sampling design of the dive survey for *C. fluminea*. There are three dive profiles (transects) spaced approximately 5 metres apart, with each profile perpendicular to the shoreline. Sampling was undertaken using quadrats and corers at multiple water depths along each profile.

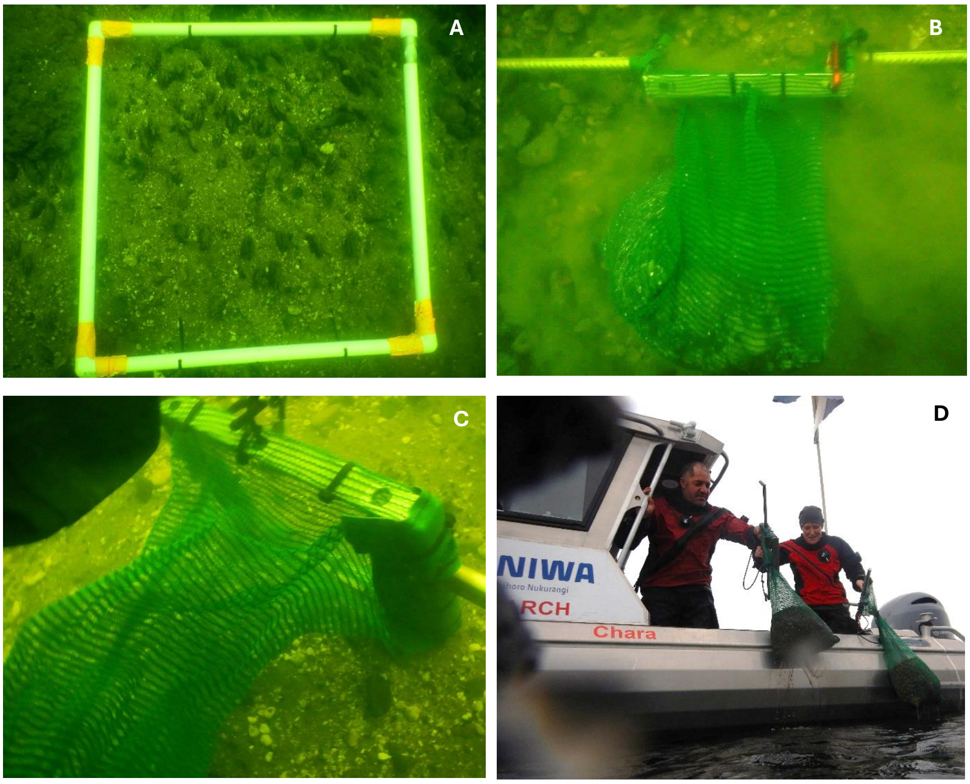

Figure 2-5: Bespoke clam net used for sampling substrates down to 10 cm sediment depths. A) 0.33 m² quadrat on the lakebed, with 0.25 by 0.25 metre sections sampled. B, C) Bespoke clam net being used by divers in Lake Maraetai. D) Divers retrieving substrate sample collected onto the boat.

Figure 2-6: Sediment sample processing procedure. **(**A) Sieving sediments through nested sieves, (B) Rinsing samples with water, (C) Identifying and counting *C. fluminea* and kaakahi.

2.4 Part B: Visual Surveillance Methods for *C. fluminea*

Once diver surveys were completed, alternative methods for sampling *C. fluminea* were tested in Lake Karaapiro at a subset of the profiles and water depths sampled by divers for Part A (at Site 3 - Horahora). The objectives of Part B, included optimising diver surveys, establishing shallow water survey protocols, undertaking shallow and deep-water comparisons, comparing alternative diver and non-diver methods. Alternative (non-diver) sample method tested aimed to match the depth range covered by the diver surveys (1 metre – 15 metres), facilitating comparison of the data collected by the different methods. Testing and development of alternative methods were to be completed after Part A and, therefore, were restricted by time and budget and were undertaken only at Site 3.

2.4.1 Alternative Diver Methods

Wisconsin net sampling

A Wisconsin net, with a 0.1 m² opening and a mesh size of 500 µm, was used to sample the top (approximate 10 cm) of the benthic substrate at each depth. Following the protocol of the original bespoke clam sampling method, three Wisconsin samples were collected and pooled to represent the substrate at each sampling site.

2.4.2 Non-Diver Methods

Benthic dredge

A benthic dredge (50 cm width x 15 cm height) was used to collect sediment samples from approximately the top 15 cm of benthic substrate at a range of water depths similar to those sampled in Part A in Lake Karaapiro. The sled comprised a robust metal frame, a metal 5 mm mesh net, a cutting blade, and a tow cable. The dredge was deployed from a boat, lowered to the lakebed, and towed for a lateral distance of approximately 17 metres at a speed of 1.4 – 1.8 km/h (Figure 2-7). As the sled moved, the cutting blade disturbed the sediment, directing it into the mesh net. This method allowed for collection of benthic material across a 0.5 metre width to a benthic substrate depth of ~15 cm over a long path area (~17 metres). The dredge could only be deployed on gentle slopes.

Figure 2-7: A) Benthic dredge on boat. B) Washing of Benthic dredge after sampling has occurred. C) Benthic dredge recovery after boat deployed at Lake Karaapiro.

Corer surveys for precise substrate sampling

UWITEC Gravity Corer

Gravity cores were used to collect high-quality, undisturbed sediment samples for assessment. To collect deep sediment samples from the lakebed, a UWITEC UC9000 gravity corer was used. This corer included a 9 cm diameter x 60 cm long tube (adjustable up to 3 metres); it was deployed vertically from a stationary boat to collect the sediment core. The corer was carefully lowered until it was about 2-3 metres above the sediment surface and allowed to stabilise. With maintaining slight tension on the line, the corer was allowed to sink into the sediment under its own weight. A messenger weight triggered the closing mechanism to trap the sediment sample within the corer tube. The corer was then slowly and steadily retrieved, ensuring the core remained intact. Upon retrieval, sediment cores (ca. 60 cm) were sliced into 10 or 15 cm sections on-site, for further processing of *C. fluminea* samples (Figure 2-8).

Figure 2-8: Gravity corer deployment (left) and corer substrate sample processing (right).

Jenkins Surface Mud Corer

The Jenkin Surface Mud Sampler was used to obtain an undisturbed sediment core (14.4 cm length x 6.9 cm diameter) for collecting data on the depth at which *C. fluminea* occur. This method ensures minimal disturbance to the sediment layers, allowing for accurate measurements of sediment composition and benthic fauna presence. This device is suitable for soft sediments but not for very compact sediments, or sediments containing larger gravel. Following the protocol by Pickup et al. (1999), the sediment samples were collected by loading the core tube into the sampler, after which the suspension rod, attached to a rope, was lifted to cock the sampler, and catch was engaged and carefully lowered into the water. Once at the desired water depth the spring mechanism was activated, and the sampler was allowed to settle into the sediments. After allowing the device to settle on the sediment for about 5 minutes, it automatically triggered and capped the core tube. The sampler was then slowly retrieved, bringing the core tube onto the boat, ensuring the collection of sediment core samples (Figure 2-9).

Figure 2-9: Jenkins Surface Mud Corer (left). Preparing it for deployment (right).

Ekman grab

The Ekman grab is a sampling device used for soft sediments free from vegetation, sticks, and leaves, as well as for areas where mixtures of sand, stones, and other coarse debris occur. The grab features a rectangular sample box (15 x 15 x 23 cm) with hinged jaws triggered by a messenger weight to snap shut and trap the sediment (Figure 2-10). This method effectively collects surface sediments up to approximately 15 cm in depth, allowing analysis to determine sediment composition and to identify benthic fauna. However, this method does not provide precise substrate depth data. The Ekman grab was deployed from the boat by lowering it to the bottom, whereafter the messenger was released to close the jaws and trap the sediment. The closed grab was then lifted back onto the boat, and the sediment was taken to shore for processing.

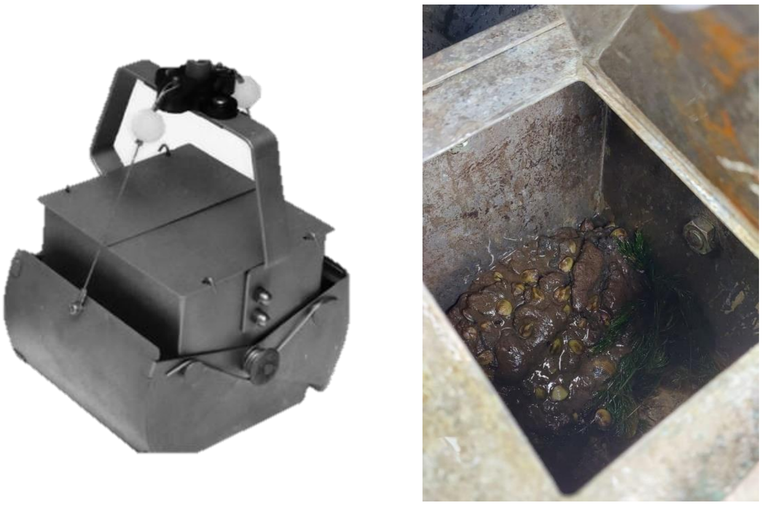

Figure 2-10: Example of Ekman grab device deployed (left). Ekman grab sampler containing sediment recovered from Lake Karaapiro (right).

2.5 Data analysis

2.5.1 Population dive survey

Average density of *C. fluminea* and kaakahi (number per m^2) per sampling site was determined. These were subsequently compared between sites. Depths of collection and length of shell (mm) were recorded and compared between sites. Histograms of *C. fluminea* and kaakahi shell lengths were constructed from counts from each site within size bins of 2 mm for *C. fluminea* and 5 mm for kaakahi (i.e., sizes 45-50 mm plotted in the 50 mm bin).

2.5.2 Alternative methods

Average density of *C. fluminea* (number per m^2) per sampling depth was determined. Efficiency of each method was calculated by dividing the *C. fluminea* count by the time (seconds) taken to collect the sample. Comparisons between sampling methods were restricted to samples taken at similar depths (shallow, mid, deep).

Size class and density data are provided separately as an .xls spreadsheet.

3 Results

3.1 Site characteristics and visual observations of *C. fluminea*

Corbicula fluminea were visible to divers at all five sites across Lake Maraetai and Lake Karaapiro, and at all sample depths across sites, except for Site 2 (Maraetai Golf course), where *C. fluminea* was not observed in the shallow 1 metre depth nor the deepest 15 metre sample. Across all five sites, *C. fluminea* were observed together with kaakahi, with visual detections of both species varying with depth, slope, and substrate type. Generally, steeper slopes were associated with observations of *C. fluminea* at mid to deep (4-15 metres) water depths. *Corbicula fluminea* was more frequently observed at mid depths, while kaakahi were consistently visually detected by divers at deeper depths across most sites. Substrates in which *C. fluminea* were found predominantly included mud, silt, sand, and gravel. *Corbicula fluminea* was found under macrophyte cover of up to 100 %, which comprised primarily invasive species (see Tables 3.1 - 3.5 and Figures 3.1 - 3.10). For physicochemical variables, see Appendix A.

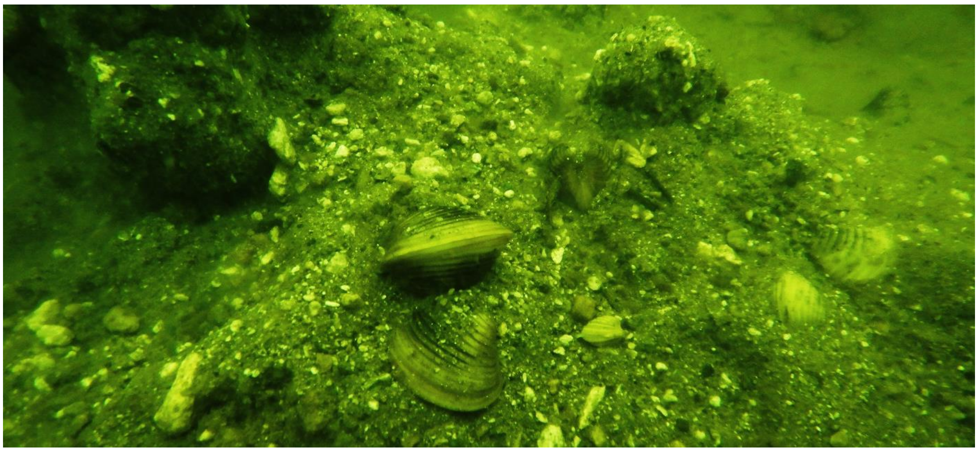

Figure 3-1: Visible *C. fluminea* at 6 metre depth at Lake Maraetai Boat ramp – Site 1.

3.1.1 Lake Maraetai Site 1 – Boat ramp

At Lake Maraetai Site 1, *C. fluminea* and kaakahi were not visually detected at 1 metre depths, which had a gentle slope of 0.09, no macrophyte cover, and substrates of sand and gravel. At 4 metres a steeper slope (0.63) prevailed and both species were visible in substrates of mud, silt, sand, and gravel, with invasive macrophyte cover ranging from 5 - 25 %. At the deep sampling depth of 15 metres, both species were consistently visible within sand and gravel substrates and under entirely invasive macrophyte cover of 100 %. Substrates transitioned to mud, silt, sand, and gravel at deeper depths (Table 3-1, Figure 3-2).

Table 3-1: Site summary characteristics at Lake Maraetai Site 1 – Boat ramp. Numbers in parentheses indicate profiles in which *C. fluminea* and/or kaakahi were visible.

Depth (m)	Profiles	*C. fluminea* visible?	Kaakahi visible?	Slope[1]	Macrophyte cover (%)	Invasive: native macrophytes	Substrate type
1	1, 2, 3	No	No	0.09	0	0:0	Sand, Gravel
4	1, 2, 3	Yes (2, 3)	Yes	0.63	5 – 25	100:0	Mud, Silt, Sand, Gravel
6	1, 2, 3	Yes	Yes	0.62	100	100:0	Sand, Gravel
9	1, 2, 3	Yes	Yes	0.68	100	100:0	Sand, Gravel, Wood
12	1, 2, 3	Yes	Yes	0.54	100	100:0	Mud, Silt, Sand
15	1, 2, 3	No	No	0.54	100	100:0	Mud, Silt, Sand, Gravel

[1] The slope values (rise over run) represent the vertical change per unit of horizontal distance. These dimensionless ratios indicate the steepness of the observed gradients, with higher values signifying steeper slopes.

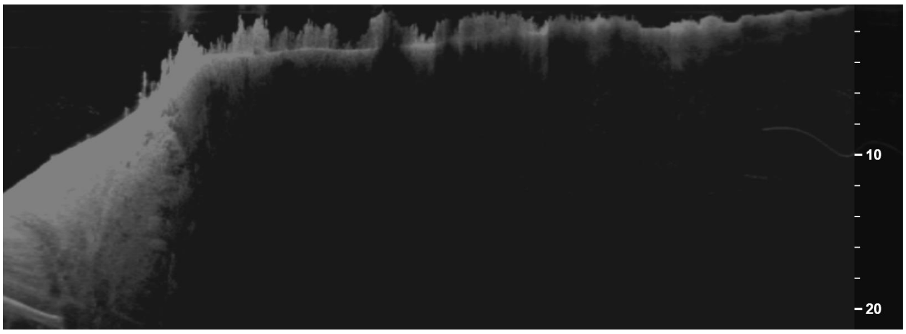

Figure 3-2: Bathymetry of Site 1 - Boat ramp at Lake Maraetai. Maximum trace distance is 122.8 metres. Top right side is the lake shore the steep gradient on the left side is a ridge leading to deeper water across the bathymetry transect.

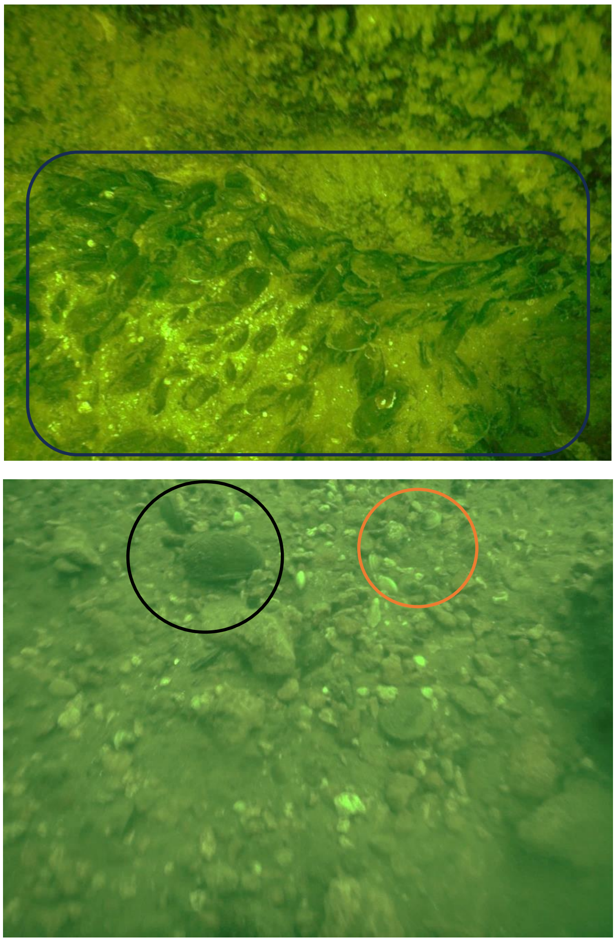

Figure 3-3: Kaakahi visually detected at 1 metre depth (top), and both *C. fluminea* and kaakahi detected at 12 metre depths at Lake Maraetai Boat ramp -Site 1. Black outline/circle shows kaakahi. Red circle shows shells of *C. fluminea.*

3.1.2 Lake Maraetai Site 2 – Golf course

Corbicula fluminea was not observed at any depths sampled. The 1 metre depth was characterised by a gentle slope, with no macrophytes visible, and muddy gravelly substrates. Kaakahi were first visible at 4 metres depth, and found in substrates primarily comprised of mud, with 100 % macrophyte cover dominated by invasive species. As depths increased, kaakahi were present across all profiles with steep slopes of 0.09 – 0.47. Substrates included mud, sand, and gravel, with invasive macrophyte cover decreasing at deeper depths (Table 3-2, Figure 3-4).

Table 3-2: Site summary characteristics at Lake Maraetai Site 2 – Golf course. Numbers in parentheses indicate profiles in which *C. fluminea* and/or kaakahi were visible.

Depth (m)	Profiles	*C. fluminea* visible?	Kaakahi visible?	Slope[1]	Macrophyte cover (%)	Invasive vs native macrophytes	Substrate type
1	1, 2, 3	No	No	0.05	0	0:0	Mud, Gravel
4	1, 2, 3	No	Yes (1,2)	0.07	100	100:0	Mud
6	1, 2, 3	No	Yes	0.09	10 – 50	100:0	Mud, Sand, Gravel
9	1, 2, 3	No	Yes	0.17	1 - 50	100:0	Mud, Silt, Sand, Gravel
12	1, 2, 3	No	Yes	0.20	1 -5	100:0	Mud, Silt
15	1, 2, 3	No	Yes	0.47	1 -5	100:0	Mud, Silt

[1] The slope values (rise over run) represent the vertical change per unit of horizontal distance. These dimensionless ratios indicate the steepness of the observed gradients, with higher values signifying steeper slopes.

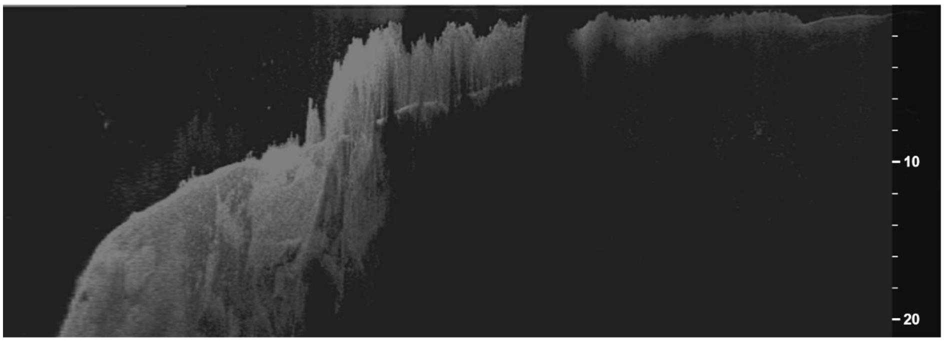

Figure 3-4: Bathymetry of Site 2 – Golf course at Lake Maraetai. Maximum trace distance is 146.7 metres. Top right side is the lake shore the steep gradient on the left side is a ridge leading to deeper water across the bathymetry transect.

3.1.3 Lake Karaapiro, Site 3 – Horahora

No *C. fluminea* or kaakahi were observed at the shallow 1-metre depth, characterised by a gentle slope, no macrophyte cover, and sand and gravel substrates. Kaakahi were first seen at 4 metres, where the slope was relatively flat, substrates were fine and macrophyte cover was 100 % (all invasive species). At 6 metres, kaakahi were consistently present with a steeper slope and a mix of sand and gravel substrates and a reduced macrophyte cover. Both *C. fluminea* and kaakahi were visible at 9 metres, within a range of silt, sand, and gravel substrates, and a macrophyte cover of 1-50 %, all invasive. At 12 and 15 metre depths, both species were observed at steep slopes, fine substrates with a low invasive macrophyte cover of 1-5 % (Table 3-3, Figure 3-5, Figure 3-6).

Table 3-3: Site summary characteristics at Lake Karaapiro Site 3 - Horahora Domain.

Depth (m)	Profiles	*C. fluminea* visible?	Kaakahi visible?	Slope[1]	Macrophyte cover (%)	Invasive vs native macrophytes	Substrate type
1	1, 2, 3	No	No	0.02	0	0:0	Sand, Gravel
4	1, 2, 3	No	Yes	0.16	100	100:0	Mud, Silt
6	1, 2, 3	No	Yes	0.42	10 – 50	100:0	Sand, Gravel
9	1, 2, 3	Yes	Yes	0.56	1 - 50	100:0	Silt, Sand, Gravel
12	1, 2, 3	Yes	Yes	0.80	1 -5	100:0	Mud, Silt
15	1, 2, 3	No	Yes	0.67	1 -5	100:0	Mud, Silt

[1] The slope values (rise over run) represent the vertical change per unit of horizontal distance. These dimensionless ratios indicate the steepness of the observed gradients, with higher values signifying steeper slopes.

Figure 3-5: Bathymetry of Site 3 – Horahora at Lake Karaapiro. Maximum trace distance is 187.2 metres. Top right side is the lake shore the steep gradient on the left side is a ridge leading to deeper water across the bathymetry transect.

Figure 3-6: Processing sediment sample from Horahora Domain, containing *C. fluminea* among macrophytes from 4 metre water depth. Orange circle shows *C. fluminea* individuals.

3.1.4 Lake Karaapiro Site 4 – Moana Roa Reserve

At Lake Karaapiro Site 4, *C. fluminea* were visible only at shallower depths, while kaakahi appeared below 4 metres depth, being found in habitats with steeper slopes and higher macrophyte cover. At 6 metres, only kaakahi were present, on the steepest slope of 0.92, with 85 % invasive macrophyte cover and a silt and gravel substrate. At 9 metres, kaakahi were seen with reduced macrophyte cover, and finer substrates. At 12 and 15 metres, only kaakahi were observed, with steep slopes of 0.80, 0.67, respectively. These sites had no macrophyte presence, and fine silty substrates (Table 3-4, Figure 3-7, Figure 3-8).

Table 3-4: Site summary characteristics at Lake Kaarapiro Site 4 – Moana Roa Reserve. Numbers in parentheses indicate profiles in which *C. fluminea* and/or kaakahi were visible.

Depth (m)	Profiles	*C. fluminea* visible?	Kaakahi visible?	Slope[1]	Macrophyte cover (%)	Invasive vs native macrophytes	Substrate type
1	1, 2, 3	Yes (1)	No	0.03	0	100:0	Silt, Gravel
4	1, 2, 3	Yes (1)	Yes	0.8	80	0:0	Silt, Gravel
6	1, 2, 3	No	Yes	0.75	85	100:0	Silt, Gravel
9	1, 2, 3	No	Yes	0.70	60	100:0	Mud, Silt
12	1, 2, 3	No	Yes	0.67	0	0:0	Silt
15	1, 2, 3	No	No	0.66	0	0:0	Silt

[1] The slope values (rise over run) represent the vertical change per unit of horizontal distance. These dimensionless ratios indicate the steepness of the observed gradients, with higher values signifying steeper slopes.

Figure 3-7: **Bathymetry of Site 4 – Moana Roa at Lake Karaapiro. Maximum trace distance is 102.2 metres.** Top right side is the lake shore the steep gradient on the left side is a ridge leading to deeper water across the bathymetry transect.

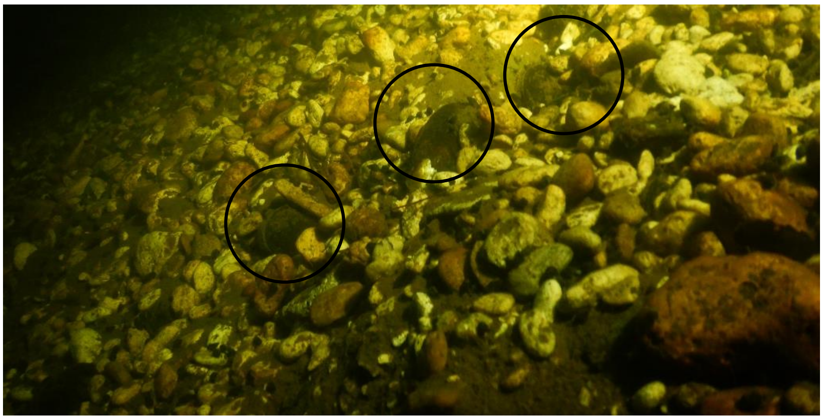

Figure 3-8: *Corbicula fluminea* siphons visible at 1 metre water depths (top) and kaakahi shells visible at 12 metre depth (bottom) at Moana Roa Reserve, Lake Karaapiro. Orange circle shows *C. fluminea* siphons. Black circles show kaakahi.

3.1.5 Lake Karaapiro Site 5 – Waipuke Park

At Site 5 - Waipuke park, *C. fluminea* was detected at shallow depths, while kaakahi were not visible until 6 metres depth. Two to 6 metre depths were characterised by a range of gentle and steeper sloping beds with 50-100 % macrophyte cover and finer substrates. At 9 metres, both species were visible, at gentle slopes and no macrophyte cover. At 12 and 15 metre depth, both species were visible; the substrates at these depths included sand and gravel (Table 3-5, Figure 3-9, Figure 3-10).

Table 3-5: Site summary characteristics at Lake Kaarapiro Site 5 – Waipuke Park. Numbers in parentheses indicate profiles in which *C. fluminea* and/or kaakahi were visible.

Depth (m)	Profiles	*C. fluminea* visible?	Kaakahi visible?	Slope[1]	Macrophyte cover (%)	Invasive vs native macrophytes	Substrate type
1	1, 2, 3	Yes (1)	No	0.06	0	0:0	Silt, Sand, Gravel
4	1, 2, 3	No	No	0.54	100	100:0	Sand, Silt
6	1, 2, 3	Yes (3)	Yes	0.28	50	100:0	Silt
9	1, 2, 3	Yes	Yes	0.07	0	0:0	Silt
12	1, 2, 3	Yes	Yes	0.43	0	0:0	Sand, Gravel
15	1, 2, 3	Yes	Yes	0.96	0	0:0	Sand, Gravel

[1] The slope values (rise over run) represent the vertical change per unit of horizontal distance. These dimensionless ratios indicate the steepness of the observed gradients, with higher values signifying steeper slopes.

Figure 3-9: Bathymetry of Site 5 – Waipuke park at Lake Karaapiro. Maximum trace distance is 204.2 m. Top right side is the lake shore the steep gradient on the left side is a ridge leading to deeper water across the bathymetry transect.

Figure 3-10: Processing a sample covered in fine silty sediment at Waipuke park.

3.2 Part A: *Corbicula fluminea* population survey

3.2.1 Detection

Corbicula fluminea population dive surveys at five sites within Lake Maraetai and Lake Karaapiro were conducted using four different detection methods. Visual observations by divers in combination with the use of bespoke clam nets and corers were used from 1 metre to 12 metre water depths, while Wisconsin net sweeps were only used at 15 metre water-depths. The bespoke clam net was significantly more effective at detecting *C. fluminea* compared to both corer samples and visual diver observations ($\chi^2 = 48.68$, df = 2, p-value = 0.001). The bespoke clam net had the highest average detection rate of (0.893, n = 68 out of 75 samples) at water depths between 1 to 12 metres. This was followed by corer samples (0.707, n = 53 out 75 samples), and visual diver observations (0.373 = 28 out of 75 samples). At 15 metre water depths, the Wisconsin net sweep detected *C. fluminea* in 11 out of 15 samples (0.733). The Wisconsin net method was excluded from statistical comparison due to its qualitative nature and limited use at a subset of sites.

The bespoke clam net consistently detected *C. fluminea* across all sites, while the Wisconsin net sweep showed 100 % detection at Sites 3, 4, and 5. The corer showed high detection at Site 4, but low detection at Site 2 where *C. fluminea* abundance was at its lowest across all sites. Visual observations were the least reliable, with no detection at Site 2, even though *C. fluminea* were present, and visual detections of *C. fluminea* were variable elsewhere.

3.2.2 Distribution across sites

The three substrate sampling methods used for population assessments (bespoke clam net, benthic corer, Wisconsin net sweep) revealed the presence of *C. fluminea* at all sample sites and depths, except for Site 2 at the Maraetai Golf Course where *C. fluminea* was not detected at depths of 1 metre and 15 metres. Across all sites and water depths within Lake Maraetai and Lake Karaapiro, a total of 12,032 *C. fluminea* individuals and 1,286 kaakahi (identified as *Echyridella menziesii*) were captured using the combined methods. The highest *C. fluminea* numbers were detected at Lake Karaapiro, Waipuke Park – Site 5, while the lowest numbers were detected at Lake Maraetai, Golf course - Site 2 (Table 3-6).

Although the corer provided a moderate detection rate for *C. fluminea* (see 3.2.1), its intact samples provided additional vertical substrate distribution data for *C. fluminea*. Specifically, intact core samples at Sites 2 and 4 indicated the presence of *C. fluminea* (n = 1 per site) at substrate depths of up to 15 cm.

Table 3-6: *Corbicula fluminea* and kaakahi counts from combined sampling methods (bespoke clam net, corer, and Wisconsin sweep net).

Lake	Site	*Corbicula fluminea* counts	Kaakahi counts
Maraetai	Boat ramp – Site 1	3757	222
Maraetai	Golf course – Site 2	76	123
Karaapiro	Horahora Domain – Site 3	1977	449
Karaapiro	Moana Roa Reserve – Site 4	1512	137
Karaapiro	Waipuke Park – Site 5	4710	355
Total		**12032**	**1286**

3.2.3 Density

Density of *C. fluminea*

Densities of *C. fluminea* were assessed using the bespoke clam net samples (i.e., quantitative samples) from 1 metre to 12 metre depths. *Corbicula fluminea* populations occurred at mean densities of 804.9 ± 1011.6 clams/m² across all sample sites in Lake Maraetai and Lake Karaapiro.

The sites are listed below in descending order of mean *C. fluminea* density.

Site 5 –Waipuke Park had the highest density, with a mean density of 1556 ± 1450 clams/m² (median: 1077 clams/m²; Figure 3-11) and a total of 4377 individuals.

Site 1 – Maraetai Boat ramp followed with a mean density of 1294 ± 1083 clams/m² (median: 1216 clams/m²), and a total of 3640 individuals collected (Figure 3-12).

Site 3 – Horahora exhibited a mean density of 650 ± 482 clams/m² (median: 400 clams/m²), with 1829 individuals collected.

Site 4 – Moana Reserve showed a mean density of 500 ± 508 clams/m² (median: 443 clams/m²), with a total of 1407 clams (Figure 3-12).

Lastly, Site 2 – Maraetai Golf Course had the lowest mean density, at 23.5 ± 30.8 clams/m² (median: 16 clams/m²), with only 66 individuals collected.

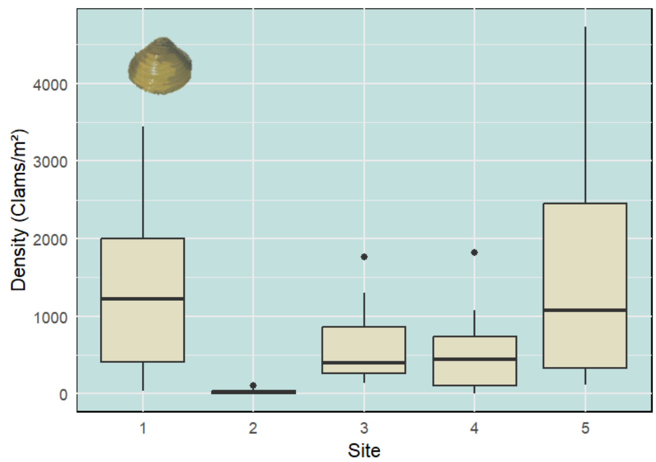

Figure 3-11: *Corbicula fluminea* densities across five sites from Lake Maraetai (Sites 1-2) and Lake Karaapiro (Sites 3-4). Boxplots show the median, interquartile range, and outliers.

Figure 3-12 *Corbicula fluminea* population at 1 metre depth at Moana Roa Reserve, Lake Karaapiro (top) and *C. fluminea* sample haul from a depth of 9 metres at Lake Maraetai Boat ramp (bottom).

While *C. fluminea* occurred at a range of depths, most aggregations predominated within deeper zones (6 metres – 15 metres) across all sites (Figure 3-13). The lowest *C. fluminea* densities appeared to occur at the shallowest depth of 1 metre, with mean densities of 56.9 ± 122.3 clams/m². In contrast, the highest densities were observed at the deepest depth of 12 metres, with mean densities of 1027.1 ± 1237.3 clams/m². As depths increased, *C. fluminea* densities generally increased as well. For instance, at 4 metres, mean densities rose to 441.7 ± 808.0 clams/m², with a range of 0 to 3072.0 clams/m². Densities further increased at 6 metres, showing a mean of 820.0 ± 706.7 clams/m², ranging from 0 to 2629.3 clams/m². At 9 metres, the mean density was 1250.0 ± 1230.6 clams/m², with values ranging from 32.0 to 3440.0 clams/m².

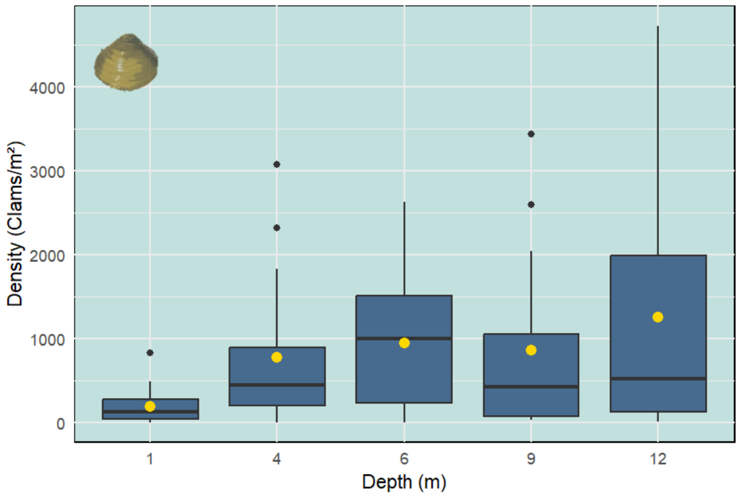

Figure 3-13: *Corbicula fluminea* densities at 1 metre, 4 metre, 6 metre, 9 metre, and 12 metre sample depths. Survey results from Lake Maraetai and Lake Karaapiro combined. Boxplots show the median, interquartile range, and outliers. Gold points show the mean.

Two-way ANOVA revealed that both site and depth had a significant effect on the density of *C. fluminea*. The effect of site was highly significant ($F_{(4, 50)}$ = 15.149, $p < 0.001$), as was the effect of depth ($F_{(4, 50)}$ = 5.909, $p < 0.001$). Moreover, there was a significant interaction between site and depth ($F_{(16, 50)}$ = 4.09, $p < 0.001$), indicating that the impact of depth on *C. fluminea* density varied depending on the site. Post hoc testing (Tukey HSD) indicated significant differences in densities between Site 1 and Site 2 ($p < 0.001$), Site 1 and Site 3 ($p < 0.01$), Site 2 and Site 5 ($p < 0.001$), and between depths of 1 and 9 metres ($p < 0.05$). Significant interaction effects were found between Site 1 at depths of 6 and 9 metres compared to 1 metre ($p < 0.05$), and between Site 5 at 12 metres compared to Site 1 at 1 metre ($p < 0.001$), highlighting a site-specific relationship between depth and *C. fluminea* density (Figure 3-14).

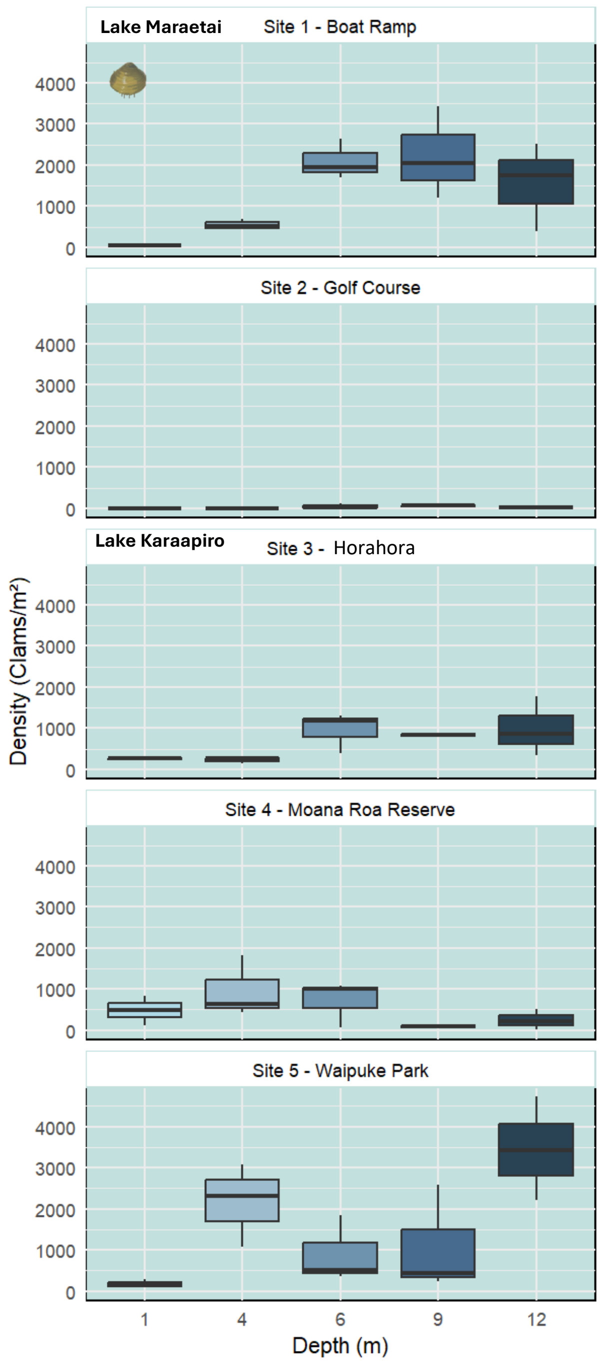

Figure 3-14: *Corbicula fluminea* densities at each site at 1 to 12 metre depths. Boxplots show the median, interquartile range, and outliers.

Density of kaakahi

For kaakahi, the average density across all sites was approximately 103.72 ± 136.8 kaakahi/m². Site 3 (Horahora Domain) had the highest densities, averaging 191.4 ± 134.2 kaakahi/m² with 479 individuals collected. In contrast, lowest mean density was observed at Site 2 (Maraetai Golf Course) – 34.9 ± 40.3 kaakahi/m², with 144 individuals. Site 5 (Waipuke Park) showed a mean density of 76.2 ± 79.6 kaakahi/m². Site 4 (Moana Reserve) and Site 1 (Maraetai Boat Ramp) had mean densities of 66.3 ± 66.5 kaakahi/m² and 81.5 ± 138.1 kaakahi/m², respectively (Figure 3-15).

The highest kaakahi densities were typically found at mid-depths of 6 -9m (Figure 3-16), and depth had a significant effect on kaakahi density (Two-Way ANOVA: ($F_{(4, 31)}$ = 2.826, p = 0.04)). At 1 metre, densities were generally low (averaging 25.2 ± 61.2 kaakahi/m²) increasing at 4 metres (average of 65.7 ± 74.4 kaakahi/m²), and reached a peak at 6 metres (average of 135.5 ± 170.3 kaakahi/m²). Kaakahi density at 6 metres was significantly higher than at 1 (mean difference = 150.71, p = 0.03) and 4 metres (mean difference = 136.18, p = 0.01). At 9 metres, the average density was 97.7 ± 115.2 kaakahi/m², and at 12 metres, it was 81.3 ± 84.9 kaakahi/m².

Although variation in kākahi density was observed between sites, the effect of site was not statistically significant ($F_{(4, 31)}$ = 2.527, p = 0.06), and there was no significant interaction between site and depth ($F_{(12, 31)}$ = 0.551, p = 0.86).

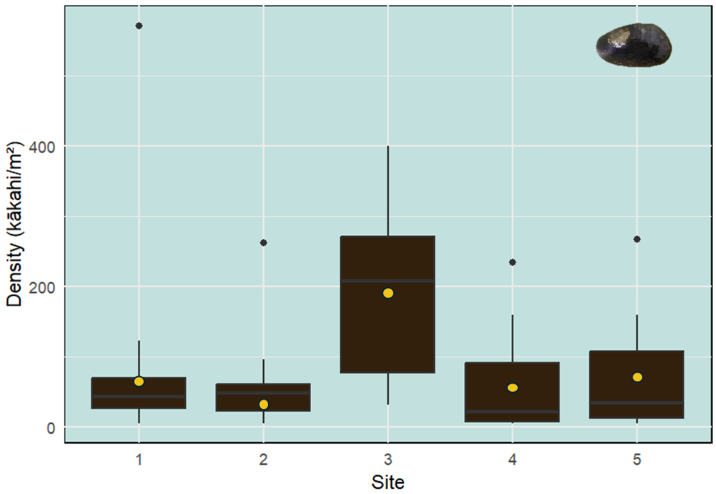

Figure 3-15: Kaakahi densities across five sites across Lake Maraetai (Sites 1-2) and Lake Karaapiro (Sites 3-4). Boxplots show the median, interquartile range, and outliers. Gold points show the mean.

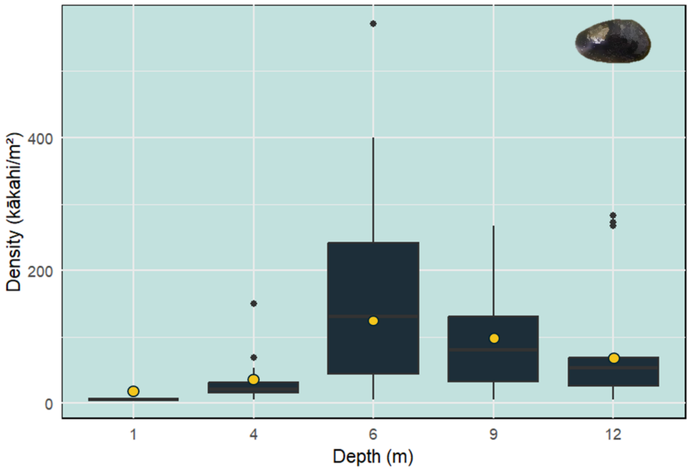

Figure 3-16: Kaakahi densities at 1 metre, 4 metre, 6 metre, 9 metre, and 12 metre sample depths. Boxplots show the median, interquartile range, and outliers.

Figure 3-17: Kaakahi collected from Lake Karaapiro Site 5 – Waipuke Park.

When comparing the densities of *C. fluminea* and kaakahi, distinct patterns emerge across sites and depths. *Corbicula fluminea* populations were most dense at Site 1 (Boat Ramp) and Site 5 (Waipuke Park), whereas kaakahi exhibited peak density at Site 3 (Horahora Domain). In terms of depth distribution, *C. fluminea* densities increased with depth, reaching a maximum at 12 metres, while kaakahi densities peaked at 6 metres, indicating a preference for mid-depth zones. Although there is clear overlap in the occurrence of *C. fluminea* and kaakahi, it appears that their patterns of density with depth differ, which may indicate differing ecological niches or habitat preferences.

3.2.4 Size

Across all sites, *C. fluminea* lengths ranged from 1 mm to 33 mm with mean lengths of 13.6±5.9 mm. Average kaakahi lengths across sites were 49.6±15.6 mm, ranging from 2 mm to 81 mm. Both *C. fluminea* and kaakahi populations demonstrated characteristics indicative of stable populations, with evidence of ongoing recruitment and multiple size classes (Figure 3-18).

At all sites (except site 2), *C. fluminea* displayed a broad range of lengths, with platykurtic (flat) distributions indicating well-established populations with multiple recruitment events. Conversely, Site 2 showed a more concentrated population with a leptokurtic (peaked) distribution, indicative of more recent establishment at this site compared with the other sites (Figure 3-18). For example, the sharp peak at 14 mm and low numbers in other size classes imply that the population is still in the initial phase of establishment, with a single cohort and recent recruitment contributing to its structure (Figure 3-18, Figure 3-19).

The differences in *C. fluminea* size with site and depth were significant ($F_{(4, 2750)} = 134.96$, $p < 0.001$; $F_{(5, 2750)} = 28.17$, $p < 0.001$, site and depth respectively) and there was a significant interaction effect between site and depth ($F_{(18, 2750)} = 12.14$, $p < 0.001$). For site comparisons, post hoc tests (Tukey HSD) revealed significant differences between Site 1 and Site 3 ($p < 0.001$), with Site 3 *C. fluminea* populations showing smaller lengths, and between Site 1 and Site 4 ($p = 0.001$), with Site 4 having greater lengths. Furthermore, Site 5 had significantly smaller lengths compared to all other sites ($p < 0.0001$).

When comparing *C. fluminea* size with depth, the lengths at 4 metres ($p = 0.001$) and 6 metres ($p < 0.001$) were significantly larger than those at 1 metre. In contrast, lengths at 9, 12, and 15 metres were significantly smaller compared to those at 4 and 6 metres.

Kaakahi populations generally exhibited signs of stability, with aging populations indicated by right-skewed distributions across all five sites, as well as evidence of recruitment events. For example young individuals were recorded across all sites, but in higher numbers at Waipuke Park (Figure 3-18, Figure 3-20).

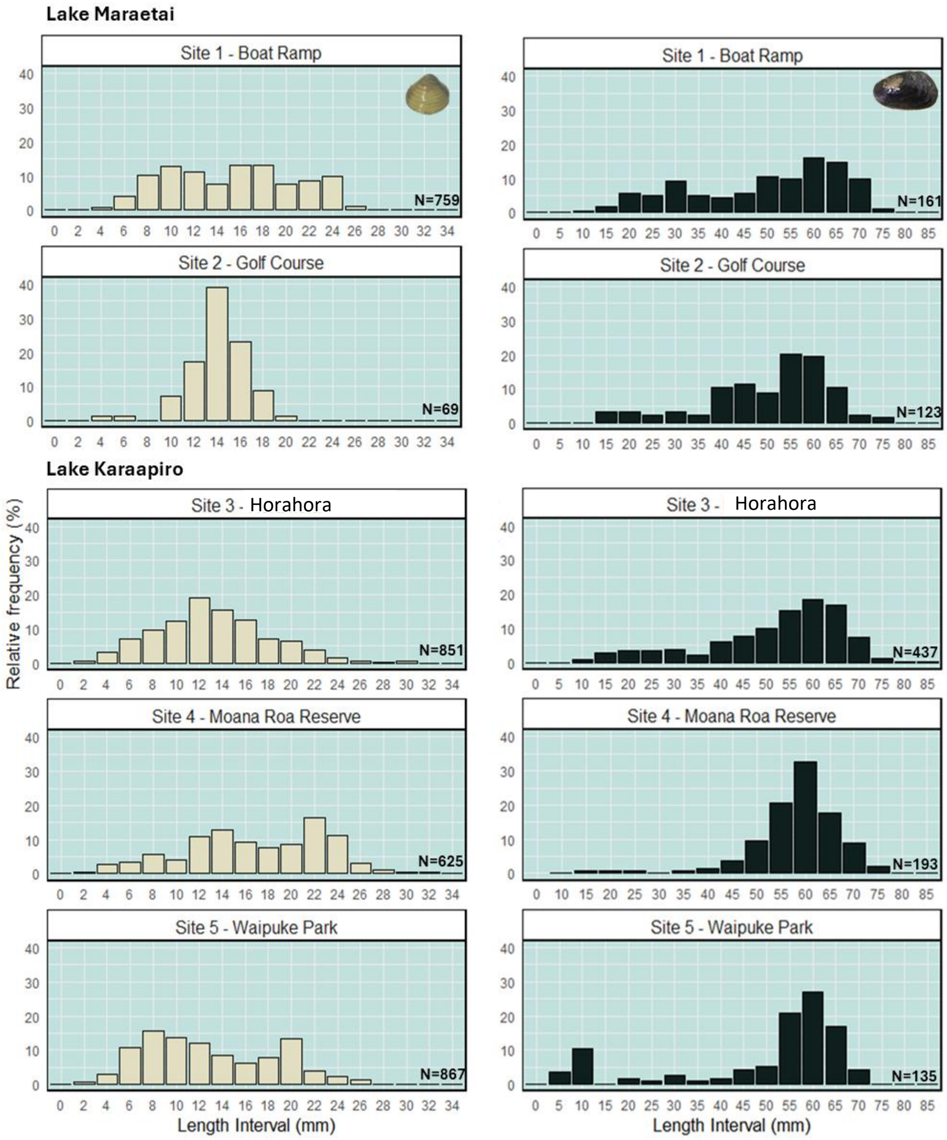

Figure 3-18: Size-frequency (%) plots of *Corbicula fluminea* (left 2 mm bins) and Kaakahi (right 5 mm bins). Observed at the five survey sites from Maraetai (Sites 1-2), and Karaapiro (sites 3-5). The histograms for *Corbicula fluminea* use 2 mm bins, while those for Kaakahi use 5 mm bins to represent the length intervals. These plots illustrate the variation in population structures across sites, showing a range of lengths from platykurtic (flat) to leptokurtic (peaked) distributions.

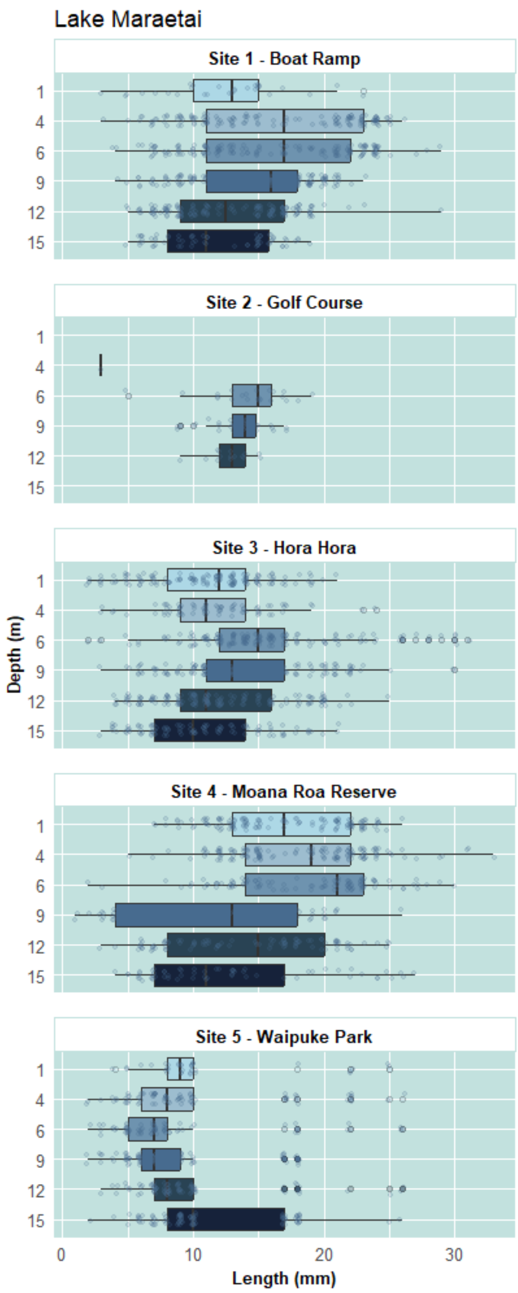

Figure 3-19. *Corbicula fluminea* length boxplots across all sites and sampling depths, 1 to 15 m. Boxplots show the median, interquartile range, and outliers. Transparency in points has been adjusted to enhance visibility of overlapping points.

Figure 3-20. Kaakahi and *C. fluminea* from Lake Maraetai. Juvenile kaakahi from the Boat ramp – Site 1 (top), juvenile and adult kaakahi at a range of different lengths (mid), and seven juvenile (<5 mm) *C. fluminea* and a mature 20 mm adult (bottom).

3.3 Part B: Alternative methods

All diver and non-diver methods detected *C. fluminea* at a range of depths within Lake Karaapiro (Site 3 Horahora). When comparing efficiency (speed of detection) and densities of clams sampled, the benthic dredge in deep waters was the most effective sampling method overall, followed by the bespoke clam net diver method at mid-depth (Table 3-7).

For the diver-operated methods, the bespoke clam net detected 17.9 clams/sec with a mean density of 1337.8 clams/m² at mid depth at 2.7 clams/sec and 208.8 clams/m² in the shallows. The Wisconsin net sweep also demonstrated moderate efficiency, with 6.8 clams/sec and a density of 1342 clams/m² at mid-depth and 1.9 clams/sec 391.7 clams/m² in the shallows. The hand-held corer was less efficient at 0.2 clams/sec in shallow waters and 6.8 clams/sec at mid-depth, had lower densities of 391.7 and 1342 clams/m², respectively (Table 3-7).

Amongst the non-diver methods, the benthic dredge had a much higher detection rate and required less operation time than the other non-diver methods, resulting in an efficiency of 16.3 clams/sec with a density of 60.7 clams/m² in deep waters. This method also performed well at mid-depths 8.2 clams/sec with a density of 28.9 clams/m².

The Ekman grab, gravity corer, and Jenkins corer showed much lower efficiencies and sampling densities. The Ekman grab had an efficiency of 0.002 clams/sec and a density of 44.4 clams/m² in shallow waters, increasing slightly to 0.15 clams/sec and 346.7 clams/m² at mid-depth. The gravity corer had efficiencies ranging from 0.01 to 0.09 clams/sec, with densities between 1047.9 and 2592.8 clams/m² across various depths. The Jenkins corer was the least efficient, not being able to detect any *C. fluminea* at shallow depths and had minimal efficiency in deep waters (Table 3-7). The substrates that were present at the site limited the use of the Jenkins corer (i.e., restricted to soft substrates).

While the gravity corer and hand-held corers had low *C. fluminea* detection efficiencies, these methods, particularly the gravity corer, were the only methods to be able to precisely determine substrate depths at which *C. fluminea* was present. Individuals were found down to 15 cm in the substrate (Figure 3-21).

Furthermore, not only was the Benthic Dredge the most efficient alternative sampling method tested, but this method was also able to detect *C. fluminea* at depths that diving methods were unable to operate given the zero light conditions beyond ca 15 metre water depth in the lake. By comparison the dredge samples detected *C. fluminea* at 30 metre depths at numbers up to 554 clams per dredge sample. However, the dredge also has its limitations, it is restricted to gently shelving slopes.

The bespoke clam net was the most efficient diver-operated method, particularly at mid-depths, with an efficiency of 17.9 clams per second.

Figure 3-21. Gravity core with *C. fluminea* found in substrates down to 15 cm depths.

Table 3-7: Summary comparing the alternative diver and non-diver methods including sampling efficiency.

	Method	No. of Samples	Area (m^2) per sample	Water depth (m)	Corbicula present	Mean count per sample	Mean density (clams per m^2)	Mean sample collection time (sec.)	Efficiency (mean no. clams per sec.)
Diver methods	Bespoke clam net	6	0.1875	Shallow (1m)	Yes	39.1	208.8	15.2	2.7
		6		Mid (12m)	Yes	250.8	1337.8	17.8	17.9
		0[1]		Deep (15–30 m)	-	-	-	-	-
	PVC handheld corer	6	0.0012	Shallow (1m)	Yes	1.7	1388.0	19.6	0.15
		7		Mid (12m)	Yes	5.2	4305.6	19.7	0.4
		0[1]		Deep (15–30 m)	-	-	-	-	-
	Wisconsin sweep	6	0.10	Shallow (1m)	Yes	35.8	358.3	19.6	1.9
		7		Mid (12m)	Yes	134.3	1342.9	19.7	6.8
		0[1]		Deep (15–30 m)	-	-	-	-	-
Non-diver methods	Benthic dredge	3	8.5	Shallow (1m)	Yes	65.3	7.6	30	2.2
		5		Mid (12m)	Yes	245.6	28.9	30	8.2
		3		Deep (15–30 m)	Yes	515.6	60.7	30	16.3
	Ekman grab	1	0.0225	Shallow (1m)	Yes	1	44.4	500	0.002
		1		Mid (12m)	Yes	78	346.7	500	0.15
		1		Deep (15–30 m)	Yes	4	177.8	500	0.01
	Gravity corer	3	0.0063	Shallow (1m)	Yes	6.7	1047.9	600	0.01
		3		Mid (12m)	Yes	5.7	890.7	600	0.09
		2		Deep (15–30 m)	Yes	16.5	2592.8	600	0.03
	Jenkins corer	0[2]	0.0225	Shallow (1m)	-	-	-	-	-
		3		Mid (12m)	Yes	2	88.6	360	0.006

		1		Deep (15–30 m))	Yes	0	-	-	-

[1]Diver methods did not include undertaking samples at deep water depths >15 metres due to health and safety considerations. Jenkins corer was restricted to deeper water depths comprising finer sediments.

4 Discussion

4.1 Population dynamics

4.1.1 Distribution

The presence of *C. fluminea* across all sample sites and water depths, except for the shallowest (1 metre) and deepest (15 metres) depths at Site 2 (Maraetai Golf Course), indicates a broad habitat range for this invasive species. *Corbicula fluminea* was found in various substrates, including mud, silt, sand, and gravel, as well as under invasive macrophytes, with cover up to 100 %. This broad habitat range aligns with previous studies highlighting the species' ability to colonise diverse aquatic habitats (Sousa et al. 2008, Lucy et al. 2012), being present in a myriad of substratum types such as mud, clay, fine and coarse sand, gravel, and even on pebbles and cobbles, and detritus (Blalock & Herod 1999, Cebulska & Krodkiewska 2019, Ciutti & Cappelletti 2009, Schrader & Brunken, 2019, Sousa et al. 2006, Skuza et al. 2009, Szarmach et al. 2023).

The co-occurrence of *C. fluminea* and kaakahi at various depths and substrates highlights the complex interactions within these ecosystems. Kaakahi were generally found in mid-depth zones, while *C. fluminea* densities increased with water depths. Understanding these interactions will be crucial for developing effective management strategies to minimise negative impacts on native species when controlling invasive *C. fluminea* populations (Strayer et al. 2006).

4.1.2 Densities

Dive surveys indicated substantial variations in *Corbicula fluminea* densities across different sites and depths. The highest average densities were recorded at Lake Maraetai Boat Ramp (Site 1) with 1,294 clams/m² and Lake Karaapiro, Waipuke Park (Site 5) with 1,556 clams/m², with some areas reaching densities exceeding 4,000 clams/m². These figures are lower compared to some international studies, where densities have been documented to be much higher. For instance, in Lake Tahoe, densities increased from 2-20 clams/m² in 2002 to over 10,000 clams/m² by 2010 due to favourable environmental conditions (Wittmann et al. 2012). Similarly, the Mississippi River exhibits densities ranging from 2,000 to 20,000 clams/m² (Hornbach 1992), the Rhine in the Netherlands reports densities of 5,000 clams/m² (bij de Vaate 1991), and the Guadalquivir River in Spain shows densities up to 10,000 clams/m² (Doherty et al. 1986).

Results of our study show that both depth and site had a significant effect on the density of *C. fluminea*. Generally, *C. fluminea* densities increased at mid to deep water depths (4 to 12 metres). This depth-dependent density pattern suggests that *C. fluminea* may prefer deeper zones at some sites, which could be attributed to stable environmental conditions and reduced predation pressures (McMahon 2002, Schmidlin & Baur 2006). Other studies have shown either a positive relationship with depth or no effect on its distribution and density (Schmidlin & Baur 2007, Cooper, 2007). In well-oxygenated lakes, *C. fluminea* have even been found at depths of 100 meters, with the greatest known depth being 143 meters in Lake Mead, USA (Peck et al. 1987). However, many studies also suggest that *C. fluminea* prefers shallow habitats (Dresler & Cory 1980, Bagatini et al. 2007, Brown et al. 2007).

The stability of substrates in deeper waters in the present study may minimise physical disturbances such as wave action and recreational activities such as boat traffic, which can negatively impact *C. fluminea* populations by causing sediment resuspension and turbulence. This stability allows for better settlement, burrowing and feeding conditions, supporting higher densities (Modesto et al. 2013, Patrick et al. 2017, Forrest et al. 2017).

The significant effect of site suggests that variations in *C. fluminea* density may be due to specific environmental characteristics inherent to each site or because of recent establishments of the population. For example, the lowest densities recorded at Site 2 (Maraetai Golf Course), likely reflects recent establishment of *C. fluminea* as evidenced by population size structure, rather than site-specific factors such as stable substrate, water flow, and levels, and mixed sediment types which have been shown to be associated with higher *C. fluminea* densities (Schmidlin & Baur 2006, Modesto et al. 2013, Paschoal et al. 2015, Forrest et al. 2017).

The interaction between site and depth implies that the impact of depth on *C. fluminea* density is not uniform across different sites. This interaction effect suggests that specific site characteristics influence how depth affects *C. fluminea* density. For example, Site 1 showed significant differences in densities at depths of 6 and 9 metres compared to 1 metre ($p < 0.05$), indicating that the physical or biological conditions at this site may support higher densities at greater depths. Conversely, at Site 5, a significant interaction effect was observed at 12 metres compared to Site 1 at 1 metre ($p < 0.001$), highlighting a unique site-specific relationship between depth and density at this location.

Sites with higher densities of *C. fluminea* may have specific attributes such as suitable sediment types, optimal nutrient levels, or favourable hydrodynamic conditions that promote colonisation and survival and growth (Modesto et al. 2013, Bolam et al. 2019). For instance, site-specific factors in our study such as slope, sediment type, and macrophyte cover were found to be associated the interaction between depth and *C. fluminea* density, underscoring the importance of considering these variables in managing this invasive species.

The observed variations in *C. fluminea* densities across different sites and depths in Maraetai and Karaapiro underscore the complexity of factors influencing the distribution of *C. fluminea*. While depth and site-specific characteristics significantly affect their densities, further research is needed to elucidate the underlying mechanisms driving these patterns.

4.1.3 Kaakahi

The lack of significant differences by site and the non-significant interaction between site and depth suggest that kaakahi populations may be influenced more by factors that are consistent across sites, such as water depth, water quality, substrate type, or broader ecological conditions, rather than site-specific factors. The lack of a significant interaction suggests that depth has a uniform effect on kaakahi density regardless of the site. These findings highlight the potential importance of regional environmental factors over local site-specific conditions in determining kaakahi density.

4.1.4 Size structure and recruitment

Length frequency distributions of *C. fluminea* indicated diverse and well-established populations at four of the five sample sites, pointing to ongoing recruitment. Sites 1, 3, 4, and 5 displayed a broad range of lengths, with platykurtic distributions indicating multiple recruitment events and stable population dynamics. In contrast, Site 2 had a more concentrated population structure with a sharp peak at 14 mm. This leptokurtic distribution, with limited size diversity at Site 2, suggests the population is in the early stages of establishment, and ongoing recruitment will contribute to its growth (Vaughn & Hakenkamp, 2001).

4.1.5 Efficiency of sampling methods for population surveys (Part A)

The use of multiple sampling methods throughout the population diver surveys was essential for establishing the vertical and spatial water depth distribution of *C. fluminea*. The visual diver observations, bespoke clam net, benthic corer, and Wisconsin sweep revealed the presence of *C. fluminea* at all sample sites and depths from 1 meter up to 15 meters. While the bespoke clam net was the most effective tool for detecting the clam compared to the corer and visual observations at depths from 1 to 12 metres, the benthic corer, despite its moderate detection rate, was instrumental in providing vertical substrate distribution data, indicating the presence of *C. fluminea* at substrate depths up to 15 cm. Visual observations, while effective at providing immediate visual confirmation of *C. fluminea* presence, were limited by factors such as water clarity and light penetration. Visual observations are likely to underestimate the presence of *C. fluminea* in poor water clarity, and individuals that are buried deeper within the substrate. The Wisconsin net was used to qualitatively detect *C. fluminea* at the deeper diver depths, complementing other methods by covering areas that were challenging for divers to sample comprehensively.

Combining these methods for future surveys of *C. fluminea* populations will ensure thorough assessments. It is important to select the appropriate method or combination of methods, to match the purpose of the survey. The selection of methods is discussed further in section 4.2, alongside the non-diver methods.

However, where divers are undertaking the sampling:

- the bespoke clam net is highly effective for quantitative population assessments to 10 cm substrate depths,
- the benthic corer is recommended for determining the vertical substrate distribution of clams, and
- the Wisconsin net sweep complements the other methods for determining the presence of *C. fluminea* especially in deeper waters to 15 metres where visibility may limit the placement of quadrats or cores.

4.2 Alternative sampling methods (Part B)

Alternative sampling methods for the detection of *C. fluminea* at a range of depths were trialled with the intention of identifying methods that would be more cost effective than diver-based surveys. The advantages and disadvantages of each method for the detection of *C. fluminea* have been summarised (Table 4-1).

The benthic dredge was the most effective, particularly in deep waters, with high detection rates (16.3 clams/sec) and densities (60.7 clams/m²). The benthic dredge samples comparatively large volumes of sediment, this enables higher detection rates than other methods, and improves the likelihood of detecting clams if they are present in low numbers. The benthic dredge was also one of the only methods to detect *C. fluminea* at greater depths (30 metres) than previously recorded in the Waikato River, highlighting its capacity to sample areas beyond the reach of divers.

These findings align with those from other studies where quite simply, the larger sampling areas (10–15 m²) of the benthic dredge, compared to smaller areas of a grab sampler or corer, increased the likelihood of encountering a species. However, the larger mesh size of the sieve in the benthic dredge (5 mm) compared to other samplers meant that only larger individuals were identified in dredge samples, contributing to potentially lower count and density, and missing size-class information that may be important depending on the purpose of the surveys (Wijman et al. 2022).

Developing a bespoke clam net for this investigation, meant that considerations of clam size and therefore mesh size were incorporated into the design, as was the need for a rigid frame that would allow the net to be pushed into the substrate to a set depth to optimise *C. fluminea* collection. While the results indicate the bespoke clam net and quadrat method were very effective, the diver limitations remain, restricting its use to mid-depth and shallower waters with adequate visibility.

Other researchers have also highlighted the effectiveness of quadrat sampling in estimating population density of *C. fluminea* (Pereira et al. 2012). They emphasised the success of quadrat-based methods when monitoring invasive bivalves but stressed the importance of considering depth and substrate type before employing quadrats. Additionally, Downing & Downing (1992) noted that using smaller quadrats with more replicates not only reduced sampling effort, such as time spent, but also decreased the variance of certain population parameters like biomass and density, supporting the practicality and efficiency of using quadrats for bivalve population studies.

While less efficient, the gravity corer and hand-held corer provided important data on vertical distribution of *C. fluminea* through the substrate, identifying them down to a depth of 15 cm. The Ekman grab and Jenkins corer were less effective, with low detection rates and low efficiency.

These results highlight the importance of selecting appropriate sampling methods based on the specific requirements of the investigation, as well as the depth and substrate analysis to optimise the detection and the study of *C. fluminea*. For example, using a benthic dredge would be a suitable method for rapid sampling across a large area to quickly determine if *C. fluminea* were present in a lake – i.e., early detection. In contrast, for assessing population density and distribution across various depths within sites, a combination of the bespoke clam net and benthic dredge would provide a balanced approach, with detailed and comprehensive data.

Table 4-1: Advantages and disadvantages for each alternative diver and non-diver survey method.

Method	Advantages	Disadvantages
Bespoke clam net	High efficiency at mid-depths. High density detection. Allows for precise, targeted sampling down to 10 cm substrate depths. Ease of use compared to more specialised equipment.	Limited to shallower depths due to diver restrictions. Can be time-consuming and labour-intensive. Requires skilled divers, increasing operational costs. Requires low turbidity for diver visibility.
Wisconsin net sweep	Moderate efficiency and density detection. Easier to use compared to more specialised equipment	Requires skilled divers, increasing operational cost. Suitable only for shallow and mid-depth sampling. Requires low turbidity for diver visibility. Can be time-consuming and labour-intensive.
Hand-held corer	Precise, targeted sampling down to 15 cm substrate depths. Easier to use compared to more specialised equipment.	Requires skilled divers, increasing operational cost. Suitable only for shallow and mid-depth sampling. Lower efficiency and density detection compared to other methods. Requires low turbidity for diver visibility.
Benthic dredge	Most efficient method in deep waters. Easier to use compared to more specialised equipment. Able to reach depths not accessible by divers (up to 30 m). High detection capacity	Disruptive to the substrate and benthic environment. Easier to use compared to more specialised equipment. Requires heavy equipment and vessel support. Limited precision compared to corers in determining exact substrate distribution. Ineffective in steep or rocky terrains, or steep slopes. Relatively large mesh size (5 mm)– may miss smaller invertebrates.
Ekman grab	Simple and easy to deploy. Able to reach depths not accessible by divers.	Requires vessel support. Limited precision compared to corers in determining exact substrate distribution. Ineffective in larger substrates or rocky terrains. Low efficiency and detection of clams.
Gravity corer	Provides precise data on substrate depths and vertical distribution. Can reach deeper substrates than most other methods. Can be deployed in shallow and deeper water depths.	Low efficiency and detection of clams, esp. at low density. Requires more time and effort to deploy. Inefficient in coarser substrates. Less suitable for rapid high-density sampling. Requires vessel support.
Jenkins corer	Can be deployed at various water depths (deep and shallow).	Requires vessel support. Lowest efficiency amongst alternative methods. Limited in providing data on clam populations. Requires fine, muddy substrates to be effective.

5 Summary and conclusions

In response to the *C. fluminea* incursion, specifications for a suppression trial were developed (Biosecurity New Zealand 2023). The primary goal outlined in the specifications, was to test and assess the effectiveness of various control methods, and to develop protocols for their rapid deployment. Before any suppression trial control work can begin, it is essential to have baseline information on where and at what densities *C. fluminea* occur. This baseline information will help identify sites where suppression trials should be undertaken, and guide selection of specific control methods that would be most effective at these sites.

5.1 Baseline summary

The summary below answers the specific questions posed by MPI that were the focus of the present investigation.

Part A: Dive surveys to determine the presence, density and population structure of *C. fluminea* in various habitats and depths.

Can *C. fluminea* be visually detected by divers?

Divers can see *C. fluminea* where there is good visibility (water clarity), but diver visual observations were not as effective as the bespoke clam net method, especially where the clams occurred at low density.

At what depths are *C. fluminea* populations located?

C. fluminea were recorded from shallow water (ca 1 m) down to 30 m.

What is the relationship between water depth and *C. fluminea* density?

C. fluminea were most dense from 6m and deeper, with highest densities observed at 12 metres. There were site specific relationships between depth and density, which may reflect the time since establishment. Observations of *C. fluminea* in shallow water cannot be used as an indicator of densities at greater water depths.

With which habitat types (e.g., substrate characteristics, bed slope, presence of macrophytes, wood, and rocks) are *C. fluminea* associated?

C. fluminea were present in all of these habitat types.

Are *C. fluminea* found beneath dense aquatic weed beds where there is limited water movement, and where low dissolved oxygen concentrations are likely to occur?

C. fluminea were recorded from samples where weedbeds were present, although generally in lesser numbers than outside of weed beds. For example, higher clam numbers were found deeper than 6 metres, while the densest weed beds occurred at 3 – 4 metre depths.

How deep are *C. fluminea* found in the sediment?

Most *C. fluminea* occurred in the top 10 cm of benthic substrate, but the deepest individuals buried in the sediment were found in core samples at 15cm substrate depth.

Part B: Develop and trial a range of alternate, cost effective, surveillance methods (including diver and non-diver methods) for detecting *C. fluminea.*

Develop a methodology that optimises efficiency and coverage of diver surveys.

The most effective diver-based survey method was the bespoke clam net. The net provided a basis for a quantitative sampling method that was achievable at all diver-accessible sites and depths.

Establish Shallow Water Survey Protocols

The bespoke clam net can be used to sample at the shoreline and shallow water to enable surveys that can be performed regularly with minimal ecological disturbance. The level of ecological disturbance will be determined by the number of samples that are taken.

Undertake Shallow- and Deep-Water Comparisons: Investigate whether observations in shallow waters may be used as an indicator of clam presence in deeper environments.

Shallow water observations alone, underestimate the abundance of *C. fluminea* across the depth gradient, particularly during the early stages of establishment where *C. fluminea* may not be observed or present in the shallows.

Explore Alternative Diver and Non-diver Methods: Areas surveyed by divers where *C. fluminea* are known to be present will be assessed further, to evaluate the feasibility of using less labour-intensive methods such as (i) Wisconsin nets (ii) Grab sampling, (iii) Benthic sleds, and (iv) Corers.

Results derived from samples collected with all of the alternative sampling methods considered, were compared with each other at the same site and at depths where the bespoke clam net method had also been used. For a non-diving, less labour-intensive approach with a high likelihood of detecting *C. fluminea*, the benthic sled was very effective. In locations where the depth of *C. fluminea* in the substrate is important, then the gravity corer should be considered. However, across the broad range of substrates sampled in this investigation the vast majority of *C. fluminea* were in the surface 10 cm of substrate, indicating that there may be little need to sample deeper.

5.2 Conclusions

Depth distribution and density data for *C. fluminea* and kaakahi were collected from five sites from Lakes Maraetai and Karaapiro that cover a range of habitats including: substrate, bed slope and invasive macrophyte cover differences. Although clams were present throughout the littoral zone, they were generally more abundant in deeper water, than shallow wadable depths.

For future surveys of *C. fluminea* populations it is important to select the appropriate method or combination of methods, to match the purpose of the survey.

It is recommended that:

- the bespoke clam net (diver operated) is used for quantitative population assessments to 10 cm substrate depths,
- benthic corers (diver, or non-diver) are used to determine the vertical substrate distribution of clams, and
- the benthic dredge (boat based) is used for rapid sampling across large area to assess *C. fluminea* presence.

The depth distribution of *C. fluminea* provides some challenges for the design and implementation of suppression trials (Step Two). For example, anchoring benthic barriers on steep littoral slopes will likely be difficult. In addition, dense weedbeds may also pose a challenge due to their bulk, and their subsequent decay after smothering that may result in 'ballooning' of a benthic barrier because gas exchange is reduced. Where weedbeds are dense these may require treatment to reduce their biomass, prior to interventions to control *C. fluminea.* There are contractors in New Zealand with expertise in the installation of benthic barriers on a range of substrates and slopes, and with weedbeds. We recommend that MPI should consult these contractors prior to commencing Step Two.

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Appendix A Physicochemical variables

Point measurements (taken at similar times each day) of environmental parameters for the surveyed sites show a range in water temperature from 12.8°C to 13.8°C. Dissolved oxygen (DO) percentages varied between 95.6% and 101.4%. Similarly, DO concentrations ranged from 9.99 mg/L at Horahora to 10.49 mg/L at Moana Reserve. pH levels across sites ranged from 7.2 to 7.6, with the lowest pH observed at Maraetai (7.2) and the highest at Horahora (7.6).

Table 7-1: Physicochemical measurements taken at each survey site at Lake Maraetai (Site 1-2) and Lake Karaapiro (3-4).

Site	Site name	Date	Temperature °C	DO %	DO mg/L	pH	River level (Masl)	Time
1	Maraetai	20/05/2024	13.6	99.9	10.39	7.5	188.7	8:45
2	Maraetai	21/05/2024	13.7	98.7	10.23	7.2	188.6	8:45
3	Horahora	22/05/2024	13.3	95.6	9.99	7.6	52.4	8:30
4	Moana Reserve	22/05/2024	13.8	101.4	10.49	7.47	52.8	8:45
5	Waipuke Park	24/05/2024	12.8	98.4	10.35	7.46	52.4	8:45

Biosecurity New Zealand
Tiakitanga Pūtaiao Aotearoa

Scientific interpretation of the Treatment trials for killing juvenile Corbicula fluminea

- The methods and results are robust and defensible from a scientific perspective.
- The **study focused on testing 2-day old or less (juveniles only)** individuals that are small, not easily seen and easily spread in or on, e.g., clothing, equipment, and water.
- It is expected that 2-day old or less individuals will be more easily killed by treatments and older and larger individuals will be more resilient. This research was specifically targeted to investigate mortality in C. fluminea juveniles given they are hard to see.
- **Extreme caution should be used in applying these results to older and larger individuals (or different species) as the dose, concentration and exposure time will need to be increased, and this does not provide certainty of achieving 100% mortality in adult clams.**
- A variety of different treatments were tested. The treatments in Table 1. were found to achieve 100 % mortality (the highlighted treatments are the most practical to implement and most cost effective).
- The highlighted results will be used to inform the Corbicula Check Clean Dry protocols, but also need to be sufficient to kill other aquatic pests (e.g., Didymo).

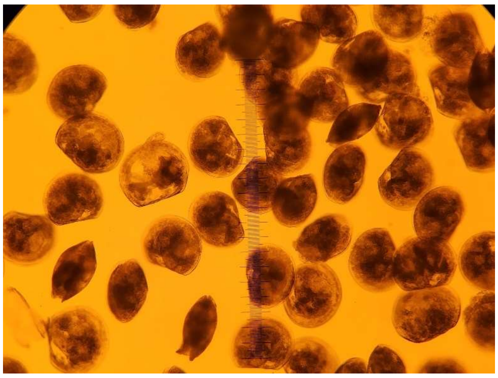
Table 1. Summary of 100 % mortality treatments and exposure times for juvenile C. fluminea.

Treatment dose / concentration	Exposure time
Water temperature 50 °C	5 min
Water temperature 70 °C	2 min
Brine 100 ppt	4 hours
Dessication (drying)	48 hours
Janola® 5 % or 3550 mg/L FAC*	10 min
Virkon® Aquatic 1 %	5 min
Virkon® Aquatic 2 %	2 min
Isopropyl Alcohol 50 %	10 min
Isopropyl Alcohol 80 %	5 min
Vinegar 20 %	10 min
Methylated spirits 40 %	10 min
Methylated spirits 40 %	10 min

Treatment trials for killing juvenile *Corbicula fluminea*

Prepared for Ministry for Primary Industries

June 2024



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Executive summary

A freshwater mollusc native to eastern Asia and often referred to as the 'freshwater gold clam' (*Corbicula fluminea*) was discovered in the Waikato River in May 2023. While the specific impacts of *C. fluminea* within a New Zealand context are not yet known, this species is recognised as an alien invasive species (AIS) throughout North and South America, and Europe, where it has caused significant harm to aquatic ecosystems and industrial infrastructure (e.g., water treatment stations). Due to these potential risks, in New Zealand *C. fluminea* has been given the legal status of an Unwanted Organism under the Biosecurity Act (1993).

The planktotrophic stage of *C. fluminea* poses a particular biosecurity challenge to manage dispersal pathways between waterbodies, due to several unique characteristics that distinguish it from other larval bivalves (e.g., robust shells and ability to produce byssal threads). Due to their small size of approximately 0.2 mm, the "invisibility" of these juveniles makes them difficult to detect and approaches are required to manage dispersal risk.

NIWA was engaged by Ministry for Primary Industries (MPI) to undertake laboratory-based trials to provide an understanding of what chemical and/or physical stressor treatments kill juvenile *C. fluminea* with 100 % efficacy (i.e., 100 % mortality). Results of this study can be used to support current biosecurity measures (e.g., Check, Clean, Dry) and consequently minimise the potential for spread of this invasive species, particularly via anthropogenic vectors such as recreational equipment and boats.

Adult *C. fluminea* were collected from Bob's Landing, Lake Karāpiro (Waikato River) and housed within a physical containment facility (PC2) at NIWA Hamilton. Following two months in the laboratory, adult *C. fluminea* survival was exceptionally high (> 99 %). Adults were spawned as required and treatment efficacy testing completed using < 48-hour old planktotrophic juveniles. The treatments evaluated were; different temperature regimes, salinity, drying, chlorine, Salt-Away®, Virkon® Aquatic, and Virkon® S, Isopropyl alcohol (IPA), vinegar (acetic acid), methylated spirits, copper and zinc to determine lethal treatment concentrations and exposure periods. Subsequent attempts to induce spawning in housed adult clams previously spawned in the laboratory resulted in a 0 % success rate for repeat spawning.

This report provides MPI with the results of the laboratory experiments. Mean juvenile *C. fluminea* survival in test control treatments was 98 %. The 100 % mortality treatments and exposure times are summarised below:

Summary of 100 % mortality treatments and exposure periods for juvenile *C. fluminea*.

Treatment dose / concentration	Exposure period
Water temperature 50 °C	5 min
Water temperature 70 °C	2 min
Brine 100 ppt	4 hours
Desiccation (drying at 20 °C and 70 % humidity)	48 hours
Janola® 5 % or 3550 mg/L FAC*	10 min
Virkon® Aquatic 1 %	5 min
Virkon® Aquatic 2 %	2 min
IPA 50 %	10 min
IPA 80 %	5 min
Vinegar 20 %	10 min
Methylated spirits 40 %	10 min

*FAC = free available chlorine

While the aim of this study was to determine treatment dose concentration and exposure periods with high mortality efficacy for juvenile *C. fluminea* in laboratory experiments, application methods need to ensure dose rates are maintained for required exposure periods to achieve 100 % mortality. Therefore, adopting a conservative approach (i.e., increased dose and/or exposure periods) is recommended to increase the certainty of achieving 100 % mortality. The potential presence of other less sensitive life stages (i.e., older individuals), and potential risks and off-target impacts of using hazardous or environmentally toxic treatments also needs to be considered.

1 Introduction

Corbicula fluminea, referred to in New Zealand as the 'freshwater gold clam', is a freshwater bivalve species native to eastern Asia. Recognised as one of the most successful freshwater invaders in the world (Sousa et al. 2008), *C. fluminea* was discovered for the first time in New Zealand in the Waikato River in May 2023. Subsequent delimitation surveys detected populations further throughout the river system (Melchior et al. 2023). While the impacts of *C. fluminea* within a New Zealand context are not yet well understood, this species has an extensive invasion history internationally, and is classified as an alien invasive species (AIS) throughout North and South America, and Europe (Modesto et al. 2023). *C. fluminea* has also recently (February 2024) been detected for the first time in Australia, in the Brisbane River, Queensland.

Invasions of *C. fluminea* have significantly impacted freshwater environments and associated infrastructure due to the species rapid reproduction, high filtration rates, and ability to form dense populations (Sousa et al. 2008). Internationally, infestations have led to severe problems for power station infrastructure, including biofouling of intake structures, clogging of cooling systems, reduction in water flow rates, and increased maintenance costs (Mackie and Claudi 2010, Wong 2023). Because of these detrimental effects on aquatic ecology and industrial infrastructure, *C. fluminea* has been classified as an Unwanted Organism under the Biosecurity Act (1993) in New Zealand. As an Unwanted Organism, *C. fluminea* must not knowingly be moved or spread (MPI 2024).

The planktotrophic stage *C. fluminea,* poses a significant biosecurity challenge, particularly regarding managing dispersal pathways between waterbodies, due to several unique characteristics that distinguish it from other larval bivalves. For example, *C. fluminea* at this stage possesses robust shells that offer greater protection against environmental stressors compared to other bivalve larvae (Nichols and Black 1994). Moreover, during their planktotrophic stage, *C. fluminea* have significant dispersal potential, which is increased further due to their ability to produce byssal threads. These threads, secreted in response to water current stimuli, act as draglines that buoy the larvae into the water column, enhancing their dispersal abilities even more (Prezant and Chalermwat 1984). Due to their small size of approximately 0.2 mm, the "invisibility" of these early juveniles makes them difficult to detect and approaches are required to manage dispersal likelihoods. At this growth stage, *C. fluminea* are essentially microscopic adults with fully formed shells (Macki and Claudi 2010), making them especially difficult to target with biocidal agents or treatments. As bivalves, they can close their shells for extended periods to protect themselves from adverse conditions, providing a degree of protection against such exposures (McMahon 2000). The ability to close their shells also complicates efforts to establish mortality compared to morbidity responses (Kramer et al. 1989).

To address these challenges, the Ministry for Primary Industries (MPI) engaged NIWA to conduct laboratory-based experimental trials aimed at to identify effective chemical or physical stressor treatments to achieve 100 % mortality rates in early growth stage *C. fluminea* (< 48-hour old planktotrophic larvae).

For a biocide to be effective, the concentration of the compound (dose rate) must be maintained within the target concentration range for a given exposure period (time) to ensure the required effect, in this case 100 % mortality.

The experiments conducted by NIWA were designed to:

1. Establish dose-response relationships for *C. fluminea* to various treatments with exposure periods up to 4 hours.
2. Allow for potential organism recovery to better establish mortality by undertaking tests using the treatment-exposure followed by a recovery period in clean water to a 96-hour total period.
3. Provide target concentration levels for in field control programmes by taking chemical/parameter measurements as required to maintain exposure conditions.

2 Methods

2.1 Permit

The work described in this report was carried out with permission obtained from MPI, including obtaining Unwanted Organism Permission to collect, transport, hold, culture, and test *C. fluminea*, ensuring regulatory compliance.

2.2 Collection, transport and holding

Between 8 January and 7 April 2024, six batches of adult *C. fluminea* specimens were collected via hand picking from Bob's Landing (37°56'50.75"S; 175°38'53.30"E), Lake Karāpiro (Waikato River).

Table 2-1: Adult *C. fluminea* collection dates, location and numbers.

Date Collected	Collection Location	# Adults collected	Lake temperature °C
8/1/24	Bob's Landing, Lake Karāpiro	400	22.1
16/2/24	Bob's Landing, Lake Karāpiro	500	-
6/3/24	Bob's Landing, Lake Karāpiro	400	-
27/3/24	Bob's Landing, Lake Karāpiro	400	-
3/4/24	Bob's Landing, Lake Karāpiro	200	-
7/4/24	Bob's Landing, Lake Karāpiro	600	18.7

Collection and transport of *C. fluminea* was conducted as per permit requirements, and no issues were encountered. Individuals were collected during the reproductive season (water temperature >15 °C) and transported to NIWA Hamilton, where they were held, cultured and tested in a PC2 containment facility (MPI Containment Facility TF00937 (568)). Specimens were held on a 16:8 (Light:Dark) light cycle at 20 °C in 50 L tanks containing approximately 3 cm of source sediment and water was aerated with no filtration. The water was supplemented weekly with 0.5 mL commercially concentrated algae stock (*Nannochloropsis* sp.) as a food source. Adult survival was monitored, and dead individuals were removed as necessary.

2.3 Spawning

Adult specimens were spawned as required to obtain planktotrophic-stage juveniles for testing. Approximately 100 adults were removed from the holding tank and transferred into a subsequent 5 L container with fresh dechlorinated tap water (Hamilton City Council; referred to as raw water hereafter) and aeration, where they were left to naturally spawn overnight. Juveniles were collected by removing adult specimens from the container, and passing the water through a 100 µm sieve, and then back flushing the juveniles into a petri dish.

Spawning success was confirmed via observation using a stereo (dissecting) microscope (Olympus SZ-6045). Here, planktotrophic larvae were analysed for maturity, characterised by fully formed translucent shells, free of their vitelline membrane (Figure 2-1).

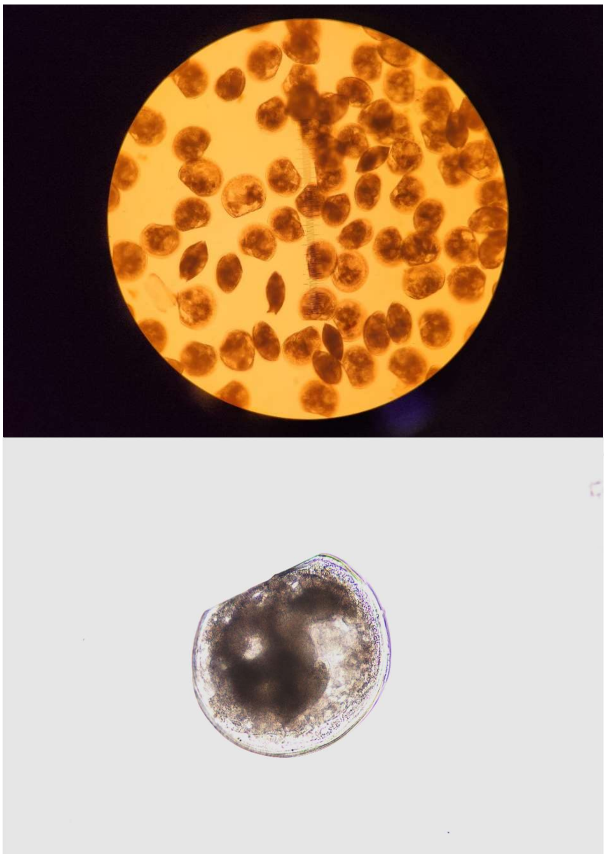

Figure 2-1: Microphotography of <24-hour old juvenile *C. fluminea* showing multiple individuals (top) and a single individual (bottom). [Images K. Thompson, NIWA]

2.4 Control survival

Following a period of acclimation, we confirmed high survival rates of juveniles could be achieved under laboratory conditions (i.e., > 90 % survival). After the first laboratory spawning, five replicates of ten active individuals (identified by observing foot movement) were isolated and transferred to 5 mL of fresh raw water in test chambers (Falcon® product 351143, Figure 2-2). After 96 hours, observations assessed the number of live versus dead juveniles, determining percent survival. Control survival tests were subsequently conducted concurrently with each round of treatment tests to ensure that each batch of spawned juveniles consistently achieved > 90 % survival.

2.5 Experimental treatments

Various treatment concentrations and exposure periods were tested to determine lethal treatments for the planktotrophic stage of *C. fluminea*. Treatments included:

- Water temperature (42 to 70 °C exposure for 2 to 10 minutes).
- Salinity (Seawater: 9 to 35 ppt exposure for 10 minutes to 96 hours; Salt brine 70 to 100 ppt exposure for 4 to 96 hours).
- Desiccation (drying) (24 to 48 hours).
- Chlorine (Janola® Regular Premium Bleach) treatment (0.001 % to 5 % exposure for 2 to 10 minutes).
- Salt-Away® (1 % to 50 % exposure for 5 minutes).
- Virkon® (Virkon® Aquatic, 0.01 % to 2 % exposure for 2 to 30 minutes; Virkon®S, 0.01 % to 1 % exposure for 10 to 30 minutes).
- Isopropyl alcohol (IPA) (20 to 90 % exposure for 2 to 10 minutes).
- Vinegar (1 to 30 % exposure for 2 to 10 minutes).
- Methylated spirits (20 % to 90 % exposure for 2 to 10 minutes).
- Copper (0.5 to 25 mg/L Cu^{2+} exposure for 5 minutes to 4 hours).
- Zinc (1 to 75 mg/L Zn^{2+} exposure for 10 minutes to 4 hours).

2.5.1 Water temperature treatment

Raw water served as the treatment solution for the water temperature manipulation. An oven was used to heat the water. The temperature was maintained upon introduction of the organisms and throughout the exposure period. After the exposure period juveniles were returned to ambient laboratory water temperature conditions (i.e., 20 °C ± 2 °C) for the recovery period.

2.5.2 Salinity treatment

NIWA's reference oceanic seawater was used for the salinity treatment. Brine was prepared by collecting the first thawed portion of frozen seawater. Salinity measurements were made using a handheld refractometer.

2.5.3 Desiccation (drying) treatment

No immersion was used for the drying treatment. Liquid was removed from test chambers and juveniles were left to desiccate at approximately 70 % humidity for each designated exposure period.

2.5.4 Chlorine treatment

The chlorine treatment used household Janola® Regular Premium Bleach sourced from a supermarket. Dilutions of the concentrated bleach solution were prepared, and the free available chlorine (FAC) concentration of each solution was measured at the start and end of each exposure period using a HACH Pocket Colorimeter™ II Chlorine Test Kit. As chlorine reacts with organic matter, as well as being lost by volatilisation and UV photolysis, it may have a rapid reduction in concentration from the initial chemical preparation or dose. FAC analysis provided assurance that the target dose concentration was maintained for each exposure period.

2.5.5 Virkon® treatment

Two formulations of Virkon® was tested, Virkon®Aquatic and Virkon®S. At the initiation of the project, Virkon®Aquatic was not commercially available in New Zealand, however the product was sourced from NIWA's Bream Bay Aquaculture Park for these experiments. Virkon®Aquatic became commercially available in February 2024. Virkon®S was obtained from Specialist Cleaning Supplies.

2.5.6 Isopropyl Alcohol (IPA), vinegar, methylated spirits treatments

IPA [CAS 67-63-0] (GR for analysis) was sourced from Merck. The vinegar treatment utilised D.Y.C Original brand white vinegar, the methylated spirits treatment used Homebrand Essentials methylated spirits (99.9 % ethanol, 0.00156 % denatonium benzoate), both sourced from a supermarket.

2.5.7 Copper and zinc treatments

The metal treatments (copper and zinc) were in their sulphate form. 100 mg/L metal ion stock solutions were prepared using milliQ UVNP (Ultra-violet Nano pure) water and then diluted with raw water to prepare test solutions.

2.6 Experimental layout and establishment

To test the effect of each treatment on survival of juvenile *C. fluminea*, < 48-hour old active planktotrophic juveniles were isolated and immersed in 5 mL of each of the prepared treatment solutions in test chambers (as per control survival tests, Figure 2-2). Treatment concentrations were prepared using raw water for dilution. At the end of each exposure period, the treatment solution was removed, and the juveniles were rinsed at least twice before being fully immersed in fresh raw water. Following designated exposure periods, individuals were left to recover (or die) to a total duration of 96 hours before survival rates were assessed using a stereo microscope.

Figure 2-2: Assessing the survival of juvenile *C. fluminea* in test chambers (5 mL) using a stereo microscope. [Image K. Thompson, NIWA]

Three types of testing were conducted to determine the impact of each treatment: including: (i) range-finder (ii) standard and (iii) confirmatory testing. Each stage of testing is described in detail below.

2.6.1 Range-finder testing

Prior to standard and confirmatory testing, range-finder experiments were performed to assist the identification of appropriate treatment concentrations and exposure periods. The range-finder treatment concentrations and exposure periods were guided by available literature (as outlined in Goulder and Wong 2024) and practical considerations regarding application. One replicate of 10 organisms for each treatment concentration-exposure combination. Individuals were observed after the recovery period to assess survival and determine if 100 % mortality (0 % survival) had been achieved. Range-finder treatments are outlined in Table 2-2.

Table 2-2: Range-finder experimental treatments and exposure periods.

Treatment	Dose/concentration	Exposure period
Water temperature	60 °C	10 min
Water temperature	70 °C	5 min
Water temperature	70 °C	10 min
Seawater	9 ppt	10 min
Seawater	18 ppt	10 min
Seawater	26 ppt	10 min
Seawater	35 ppt	10 min
Seawater	35 ppt	96 hours
Brine	70 ppt	96 hours
Janola®	0.001 %	10 min
Janola®	0.01 %	10 min
Janola®	0.1 % or 77 mg/L FAC*	10 min
Janola®	1 % or 750 mg/L FAC*	10 min
Virkon® Aquatic/S	0.01 %	10 min
Virkon® Aquatic/S	0.1 %	10 min
Virkon® Aquatic/S	0.5 %	10 min
Virkon® Aquatic/S	1 %	10 min
Virkon® Aquatic/S	1 %	30 min
IPA	20 %	5 min
IPA	40 %	5 min
IPA	40 %	10 min
Vinegar	1 %	5 min
Vinegar	5 %	5 min
Vinegar	10 %	5 min
Methylated spirits	20 %	10 min

Treatment	Dose/concentration	Exposure period
Methylated spirits	35 %	5 min
Methylated spirits	50 %	5 min
Cu^{2+}	0.5 mg/L	10 min
Cu^{2+}	1 mg/L	10 min
Cu^{2+}	2 mg/L	10 min
Cu^{2+}	6.25 mg/L	10 min
Cu^{2+}	6.25 mg/L	2 hours
Cu^{2+}	12.5 mg/L	10 min
Cu^{2+}	12.5 mg/L	2 hours
Cu^{2+}	25 mg/L	10 min
Cu^{2+}	25 mg/L	2 hours
Cu^{2+}	25 mg/L	4 hours
Zn^{2+}	1 mg/L	10 min
Zn^{2+}	2 mg/L	10 min
Zn^{2+}	4 mg/L	10 min
Zn^{2+}	12.5 mg/L	10 min
Zn^{2+}	25 mg/L	10 min
Zn^{2+}	50 mg/L	10 min
Zn^{2+}	75 mg/L	10 min

*FAC = free available chlorine

2.6.2 Standard testing

Standard testing involved a narrower range of treatments (concentration and exposure period combinations) compared to range-finder testing. Each test included three replicates of 10 organisms. Survival was assessed after the recovery period by counting the number of live versus dead juveniles, and the mean mortality percentage was calculated for each treatment. Initial physico-chemical parameters were measured (Table A-1). Standard testing treatments are outlined in Table 2-3.

Table 2-3: Standard testing experimental treatments and exposure periods.

Treatment	Dose/concentration	Exposure period
Water temperature	60 °C	2 min
Water temperature	60 °C	5 min
Water temperature	70 °C	2 min
Water temperature	70 °C	5 min
Brine	100 ppt	4 hours
Brine	100 ppt	24 hours
Brine	100 ppt	96 hours
Desiccation (drying)	20 °C and 70 % humidity	24 hours
Desiccation (drying)	20 °C and 70 % humidity	48 hours
Janola®	0.05 %	5 min

Treatment	Dose/concentration	Exposure period
Janola®	0.05 %	10 min
Janola®	0.1 % or 77mg/L FAC*	2 min
Janola®	0.1 % or 77mg/L FAC*	5 min
Janola®	0.1 % or 77mg/L FAC*	10 min
Janola®	0.5 % or 370 mg/L FAC*	2 min
Janola®	0.5 % or 370 mg/L FAC*	5 min
Janola®	0.5 % or 370 mg/L FAC*	10 min
Janola®	1 % or 750mg/L FAC*	5 min
Janola®	1 % or 750mg/L FAC*	10 min
Janola®	2 % or 1575 mg/L FAC*	5 min
Janola®	2 % or 1575 mg/L FAC*	10 min
Janola®	5 % or 3550 mg/L FAC*	10 min
Salt-Away®	1 %	5 min
Salt-Away®	20 %	5 min
Salt-Away®	50 %	5 min
Virkon® Aquatic	0.1 %	5 min
Virkon® Aquatic	0.5 %	2 min
Virkon® Aquatic	0.5 %	5 min
Virkon® Aquatic	1 %	2 min
Virkon® Aquatic	1 %	5 min
Virkon® Aquatic	1 %	10 min
Virkon® Aquatic	2 %	2 min
Virkon® Aquatic	2 %	5 min
IPA	30 %	5 min
IPA	30 %	10 min
IPA	40 %	2 min
IPA	40 %	5 min
IPA	40 %	10 min
IPA	50 %	2 min
IPA	50 %	10 min
IPA	70 %	5 min
IPA	80 %	5 min
IPA	90 %	2 min
Vinegar	5 %	5 min
Vinegar	10 %	5 min
Vinegar	20 %	2 min
Vinegar	20 %	5 min
Vinegar	20 %	10 min
Vinegar	30 %	2 min

Treatment	Dose/concentration	Exposure period
Methylated spirits	30 %	5 min
Methylated spirits	40 %	2 min
Methylated spirits	40 %	5 min
Methylated spirits	50 %	2 min
Methylated spirits	80 %	5 min
Methylated spirits	90 %	2 min
Cu^{2+}	6.25 mg/L	2 hours
Cu^{2+}	12.5 mg/L	2 hours
Cu^{2+}	25 mg/L	5 min
Cu^{2+}	25 mg/L	10 min
Cu^{2+}	25 mg/L	2 hours
Cu^{2+}	25 mg/L	4 hours
Zn^{2+}	15 mg/L	10 min
Zn^{2+}	50 mg/L	10 min
Zn^{2+}	75 mg/L	10 min

*FAC = free available chlorine

2.6.3 Confirmatory testing

To provide a higher degree of certainty of test results confirmatory testing was conducted following standard testing. Treatments that had 100 % mortality (i.e., 0% survival) during standard testing were re-tested using one replicate of 100 organisms. Initial physico-chemical parameters were measured (Table A-1). Survival was assessed after the recovery period by counting the number of live versus dead juveniles to determine the mortality percentage of each treatment. Confirmatory testing treatments are outlined in Table 2-4.

Table 2-4: Confirmatory testing experimental treatments and exposure periods.

Treatment	Dose/concentration	Exposure period
Water temperature	42 °C	5 min
Water temperature	50 °C	5 min
Water temperature	55 °C	5 min
Water temperature	60 °C	5 min
Water temperature	70 °C	2 min
Brine	100 ppt	4 hours
Desiccation (drying)	20 °C and 70 % humidity	48 hours
Janola®	2 % or 1575 mg/L FAC*	10 min
Janola®	5 % or 3550 mg/L FAC*	10 min
Virkon® Aquatic	0.5 %	10 min
Virkon® Aquatic	1 %	5 min
Virkon® Aquatic	2 %	2 min
IPA	40 %	10 min

Treatment	Dose/concentration	Exposure period
IPA	50 %	10 min
IPA	80 %	5 min
Vinegar	20 %	5 min
Vinegar	20 %	10 min
Vinegar	30 %	2 min
Methylated spirits	40 %	5 min
Methylated spirits	40 %	10 min
Cu^{2+}	6.25 mg/L	2 hours
Cu^{2+}	12.5 mg/L	2 hours
Cu^{2+}	25 mg/L	2 hours
Cu^{2+}	25 mg/L	4 hours
Zn^{2+}	50 mg/L	2 hours
Zn^{2+}	50 mg/L	4 hours
Zn^{2+}	75 mg/L	10 min

*FAC = free available chlorine

3 Results and discussion

3.1 Collection, transport and holding

Approximately 2500 adult *C. fluminea* were collected between 8 January and 7 April 2024. During transportation from the collection site to the laboratory, spontaneous spawning of some adult clams occurred. Subsequent attempts to induce spawning in clams previously spawned in the laboratory resulted in a 0 % success rate.

Following two months in the laboratory, adult survival remained high at > 99 %.

3.2 Treatment trials

High juvenile survival rates were achieved during initial laboratory survival tests (> 90 % survival). Initial juvenile 96-hour survival (n=5 replicates) was 100 % and thus treatment testing was initiated. Subsequent control tests resulted in juvenile 96-hour survival rates of 98 % (n=21 replicates), with all replicates demonstrating greater than 90 % survival. Relevant physicochemical and free available chlorine (FAC) measures of test solutions are provided in Appendix A (Table A-1).

3.2.1 Water temperature treatment

All range-finder treatments were 100 % effective at killing juvenile *C. fluminea*. Subsequent testing indicated that a 60 °C treatment with a 5-minute exposure was required to achieve 100 % mortality. At 70 °C a 2-minute exposure was required to achieve 100 % mortality. These results were verified with confirmatory testing, the testing also revealed that the minimum temperature to remain 100% effective is 50 °C with a 5-minute exposure (Table 3-1).

Table 3-1: *C. fluminea* mortality with various water temperature treatments.

Treatment dose / concentration	Exposure period	Range-finder 100 % mortality Y/N	Standard testing mean % mortality	Confirmatory testing % mortality
Water 42 °C	5 min	-	-	88
Water 50 °C	5 min	-	-	100
Water 55 °C	5 min	-	-	100
Water 60 °C	2 min	-	97	-
Water 60 °C	5 min	-	100	100
Water 60 °C	10 min	Y	-	-
Water 70 °C	2 min	-	100	100
Water 70 °C	5 min	Y	100	-
Water 70 °C	10 min	Y	-	-

3.2.2 Salinity treatment

No range-finder salinity treatments were 100 % effective at killing juvenile *C. fluminea*. Subsequent testing with 100 ppt brine treatments for exposure periods of 4, 24 and 96 hours provided 100 % efficacy for killing juvenile *C. fluminea.* 100 % efficacy was subsequently confirmed for the 100 ppt treatment at 4 hours exposure (Table 3-2).

Table 3-2: *C. fluminea* mortality with various salinity treatments.

Treatment dose / concentration	Exposure period	Range-finder 100 % mortality Y/N	Standard testing mean % mortality	Confirmatory testing % mortality
Seawater 9 ppt	10 min	N		
Seawater 18 ppt	10 min	N		
Seawater 26 ppt	10 min	N		
Seawater 35 ppt	10 min	N		
Seawater 35 ppt	96 hours	N	-	-
Brine 70 ppt	96 hours	N	-	-
Brine 100 ppt	4 hours	-	100	100
Brine 100 ppt	24 hours	-	100	-
Brine 100 ppt	96 hours	-	100	-

3.2.3 Desiccation (drying) treatment

No range-finder testing was carried out for the drying treatment. Standard testing was undertaken for drying treatments at exposure periods of 24 and 48 hours (Table 2-3). The 48-hour treatment provided 100 % efficacy in killing juvenile *C. fluminea* and these results were validated in subsequent confirmatory testing (

Temperature and relative humidity significantly affect the desiccation (drying out) of *C. fluminea* and must be considered when using desiccation as a biosecurity measure for *C.fluminea*. At lower temperatures and higher relative humidity levels, the ambient moisture content in the air reduces the rate of water loss from the organisms, potentially prolonging their survival outside of water. Conversely, higher temperatures and lower relative humidity accelerates desiccation and mortality by increasing the rate of water loss (Guareschi and Wood 2020).

Table 3-3).

Temperature and relative humidity significantly affect the desiccation (drying out) of *C. fluminea* and must be considered when using desiccation as a biosecurity measure for *C.fluminea*. At lower temperatures and higher relative humidity levels, the ambient moisture content in the air reduces the rate of water loss from the organisms, potentially prolonging their survival outside of water. Conversely, higher temperatures and lower relative humidity accelerates desiccation and mortality by increasing the rate of water loss (Guareschi and Wood 2020).

Table 3-3: *C. fluminea* mortality with various desiccation (drying) treatments at 20 °C and 70 % humidity.

Treatment dose / concentration	Exposure period	Standard testing mean % mortality	Confirmatory testing % mortality
Drying at 20 °C and 70 % humidity	24 hours	93	-
Drying at 20 °C and 70 % humidity	48 hours	100	100

3.2.4 Chlorine (Janola® Regular Premium Bleach) treatment

Initial Janola® bleach range-finder testing showed that 0.1 % and 1 % treatments for a 10-minute exposure period achieved 100 % mortality. Therefore, standard testing was undertaken with 0.05 %, 0.1 % and 0.5 % bleach with 2- to 10-minute exposure periods. However, none of these treatments achieved 100 % mortality.

Further testing was undertaken with 0.1 %, 0.5 %, 1 %, 2 % and 5 % bleach with 5- to 10-minute exposure periods. Bleach treatments of 2 % and 5 % with 10 minutes exposure achieved 100 % mortality. However, subsequent confirmatory testing showed that while the 10-minute exposure to 5 % bleach (initial concentration, 3550 mg/L FAC (Table A-1)) had 100 % efficacy, 2 % bleach (initial concentration, 1100 mg/L FAC (Table A-1)) for the same period provided 99 % efficacy (

Table 3-4).

Table 3-4: *C. fluminea* mortality with various Chlorine (Janola® Regular Premium Bleach) treatments.

Treatment dose / concentration*	Exposure period	Range-finder 100 % mortality Y/N	Standard testing mean % mortality	Confirmatory testing % mortality
Janola® 0.001 %	10 min	N	-	-
Janola® 0.01 %	10 min	N	-	-
Janola® 0.05 %	5 min	-	50	-
Janola® 0.05 %	10 min	-	60	-
Janola® 0.1 % or 77mg/L FAC	2 min	-	83	-
Janola® 0.1 % or 77mg/L FAC	5 min	-	67	-
Janola® 0.1 % or 77mg/L FAC	10 min	Y	52	-
Janola® 0.5 % or 370 mg/L FAC	2 min	-	77	-
Janola® 0.5 % or 370 mg/L FAC	5 min	-	70	-
Janola® 0.5 % or 370 mg/L FAC	10 min	-	27	-
Janola® 1 % or 750 mg/L FAC	5 min	-	28	-
Janola® 1 % or 750 mg/L FAC	10 min	Y	22	-
Janola® 2 % or 1575 mg/L FAC	5 min	-	87	-
Janola® 2 % or 1575 mg/L FAC	10 min	-	100	99
Janola® 5 % or 3550 mg/L FAC	10 min	-	100	100

* FAC = free available chlorine

3.2.5 Salt-Away® treatment

No range-finder testing was carried out for this treatment. The 50 % Salt-Away® treatment was effective with a 5-minute exposure (Table 3-5). However, this 1:1 ratio is significantly more concentrated than the standard recommended application rate of 512:1 making it impractical and expensive, hence confirmatory testing was not conducted.

Table 3-5: *C. fluminea* mortality with various Salt-Away® treatments.

Treatment dose / concentration	Exposure period	Standard testing mean % mortality	Confirmatory testing % mortality
Salt-Away® 1 %	5 min	80	-
Salt-Away® 20 %	5 min	87	-
Salt-Away® 50 %	5 min	100	-

3.2.6 Virkon® Aquatic/S treatments

Range-finder and standard testing showed comparable results between Virkon® Aquatic and Virkon® S. Confirmatory testing confirmed that 1 % and 2 % Virkon® Aquatic achieved 100 % mortality with 5- and 2- minute exposure periods, respectively (Table 3-6).

Table 3-6: *C. fluminea* mortality with various Virkon® treatments.

Treatment dose / concentration	Exposure period	Range-finder 100 % mortality Y/N	Standard testing mean % mortality	Confirmatory testing % mortality
Virkon® Aquatic/S 0.01 %	10 min	N	-	-
Virkon® Aquatic 0.1 %	5 min	-	70	-
Virkon® Aquatic/S 0.1 %	10 min	Y	-	-
Virkon® Aquatic 0.5 %	2 min	-	83	-
Virkon® Aquatic 0.5 %	5 min	-	87	-
Virkon® Aquatic/S 0.5 %	10 min	Y	-	98[*]
Virkon® Aquatic 1 %	2 min	-	83	-
Virkon® Aquatic 1 %	5 min	-	100	100
Virkon® Aquatic/S 1 %	10 min	Y	100[a]	-
Virkon® Aquatic/S 1 %	30 min	Y	-	-
Virkon® Aquatic 2 %	2 min	-	100	100
Virkon® Aquatic 2 %	5 min	-	100	-

[*] Only Virkon® Aquatic tested.

3.2.7 Isopropyl Alcohol (IPA) treatment

During initial range-finder testing with IPA, a 40 % treatment was effective at 5 and 10 minutes exposure. However, standard testing and confirmatory testing proved that 40 % IPA was less than 100 % effective. Subsequent confirmatory testing showed 50 % IPA with a 10-minute exposure or 80 % IPA with a 5-minute exposure are minimum requirements for killing juvenile *C. fluminea*. No treatments with a 2-minute exposure were 100 % effective (Table 3-7).

Table 3-7: *C. fluminea* mortality with various Isopropyl alcohol (IPA) treatments.

Treatment dose / concentration	Exposure period	Range-finder 100 % mortality Y/N	Standard testing mean % mortality	Confirmatory testing % mortality
IPA 20 %	5 min	N	-	-
IPA 30 %	5 min	-	86	-
IPA 30 %	10 min	-	95	-
IPA 40 %	2 min	-	17	-
IPA 40 %	5 min	Y	69	-
IPA 40 %	10 min	Y	100	94
IPA 50 %	2 min	-	78	-
IPA 50 %	10 min	-	100	100
IPA 70 %	5 min	-	77	-
IPA 80 %	5 min	-	100	100
IPA 90 %	2 min	-	92	-

3.2.8 Vinegar treatment

Initial range-finder testing showed that vinegar achieved 100 % mortality at concentrations of 5 % and higher. However, the standard testing produced conflicting results. Standard testing was undertaken with 5 % and 10 % vinegar for 5 minutes and 20 % vinegar for 2 minutes. None of these treatments were 100 % effective, contrary to the initial range-finder test results.

Further testing was undertaken with 20 % vinegar for 5 and 10 minutes and 30 % vinegar for 2 minutes, 100 % mortality was achieved with each treatment. However, again confirmatory testing produced conflicting results with the 20 % vinegar treatment for 10 minutes the only treatment providing effective results (Table 3-8).

Table 3-8: *C. fluminea* mortality with various vinegar treatments.

Treatment dose / concentration	Exposure period	Range-finder 100 % mortality Y/N	Standard testing mean % mortality	Confirmatory testing % mortality
Vinegar 1 %	5 min	N	-	-
Vinegar 5 %	5 min	Y	53	-
Vinegar 10 %	5 min	Y	73	-
Vinegar 20 %	2 min	-	73	-
Vinegar 20 %	5 min	-	100	93
Vinegar 20 %	10 min	-	100	100
Vinegar 30 %	2 min	-	100	92

3.2.9 Methylated spirits treatment

The 50 % methylated spirits treatment with a 5-minute exposure was the only treatment that provided 100 % mortality in the range-finder testing.

Results from the standard testing showed that 40 % (and 80 %) methylated spirits for 5 minutes was 100 % effective. However, confirmatory testing indicated that a 5-minute exposure to 40 % vinegar was insufficient and that a 10-minute exposure is required at this concentration to achieve 100 % mortality (Table 3-9).

Table 3-9: *C. fluminea* mortality with various methylated spirits treatments.

Treatment dose / concentration	Exposure period	Range-finder 0 % mortality Y/N	Standard testing mean % mortality	Confirmatory testing % mortality
Methylated spirits 20 %	10 min	N	-	-
Methylated spirits 30 %	5 min	-	73	-
Methylated spirits 35 %	5 min	N	-	-
Methylated spirits 40 %	2 min	-	10	-
Methylated spirits 40 %	5 min	-	100	91
Methylated spirits 40 %	10 min	-	-	100
Methylated spirits 50 %	2 min	-	28	-
Methylated spirits 50 %	5 min	Y	-	-
Methylated spirits 80 %	5 min	-	100	-
Methylated spirits 90 %	2 min	-	90	-

3.2.10 Copper treatment

Initial range-finder testing showed that 6.25 mg/L Cu^{2+} and higher concentrations with a 10-minute exposure period was 100 % effective for killing juvenile *C. fluminea*. Hence, standard testing was initially undertaken with 25 mg/L Cu^{2+} in 5- and 10-minute exposures, however results showed that neither treatment provided 100 % mortality. Further testing was undertaken with additional concentrations (6.25 mg/L $Cu^{2+}$and 12.5 mg/L Cu^{2+}) and longer exposure periods (2 and 4 hours). A 2-hour exposure at 6.25 mg/L Cu^{2+} caused 100 % mortality, however confirmatory testing indicated that even with a 4-hour exposure to 25 mg/L, Cu^{2+} did not sufficiently kill *C. fluminea,* with 1 % surviving (Table 3-10). No further testing or confirmatory testing was undertaken as it was considered the use of copper at such high concentrations would pose a significant environmental hazard and longer exposure periods would make application impractical.

Table 3-10: *C. fluminea* mortality with various copper treatments.

Treatment dose / concentration	Exposure period	Range-finder 100 % mortality Y/N	Standard testing mean % mortality	Confirmatory testing % mortality
0.5 mg/L Cu^{2+}	10 min	N	-	-
1 mg/L Cu^{2+}	10 min	N	-	-
2 mg/L Cu^{2+}	10 min	N	-	-

6.25 mg/L Cu^{2+}	10 min	Y	-	-
6.25 mg/L Cu^{2+}	2 hours	Y	100	93
12.5 mg/L Cu^{2+}	10 min	Y	-	-
12.5 mg/L Cu^{2+}	2 hours	Y	100	96
25 mg/L Cu^{2+}	5 min	-	83	-
25 mg/L Cu^{2+}	10 min	Y	80	-
25 mg/L Cu^{2+}	2 hours	Y	100	95
25 mg/L Cu^{2+}	4 hours	Y	100	99

3.2.11 Zinc treatment

All zinc treatments (1 to 4 mg/L Zn^{2+} exposed for 10 minutes) had surviving organisms at the end of the recovery period in range-finder testing. Further range-finder tests were conducted with 12.5, 25, 50 and 75 mg/L Zn^{2+} at 10-minute exposures. All of these treatments provided 100 % mortality. Standard testing was undertaken with 15, 50 and 75 mg/L Zn^{2+} with 10-minute exposure periods, however results showed that none of these treatments provided 100 % mortality with survival ranging from 30-70 %.

Confirmatory testing was undertaken for the 50 mg/L Zn^{2+} treatment with longer exposure periods (2 and 4 hours), but again neither produced 100 % mortality, with 4 % survival after a 4-hour exposure (Table 3-11). No further testing was undertaken as it was considered that the use of such high concentrations of zinc would pose a significant environmental hazard and use of longer exposure periods would make application impractical.

Table 3-11: *C. fluminea* mortality with various zinc treatments.

Treatment dose / concentration	Exposure period	Range-finder 100 % mortality Y/N	Standard testing mean % mortality	Confirmatory testing % mortality
1 mg/L Zn^{2+}	10 min	N	-	-
2 mg/L Zn^{2+}	10 min	N	-	-
4 mg/L Zn^{2+}	10 min	N	-	-
12.5 mg/L Zn^{2+}	10 min	Y	-	
15 mg/L Zn^{2+}	10 min	-	30	-
25 mg/L Zn^{2+}	10 min	Y	-	-
50 mg/L Zn^{2+}	10 min	Y	70	-
50 mg/L Zn^{2+}	2 hours	-	-	94
50 mg/L Zn^{2+}	4 hours	-	-	96
75 mg/L Zn^{2+}	10 min	Y	63	-

4 Conclusion and recommendations

Survival rates of laboratory-housed adults of *C. fluminea* exceeded 99 % over a minimum period of two months. This study demonstrates that laboratory-based spawning is easily achieved with high 96-hour survival rates in recently spawned juveniles that enables testing. Generally, subsequent attempts to induce spawning with clams that had previously spawned in the laboratory was unsuccessful.

These trials have identified several treatments that are effective in achieving 100 % mortality of juvenile *C. fluminea* (Table 4-1). Some of the treatments tested are regarded as unreliable or impractical (i.e., Salt-Away®, copper and zinc). While effective treatments have been identified in these laboratory trials, their field application requires consideration of the target life stage, environmental and logistical factors.

Table 4-1: Summary of 100 % mortality treatments and exposure periods for juvenile *C. fluminea*.

Treatment dose / concentration	Exposure period
Water temperature 50 °C	5 min
Water temperature 70 °C	2 min
Brine 100 ppt	4 hour
Desiccation (drying at 20 °C and 70 % humidity)	48 hour
Janola® 5 % or 3550 mg/L FAC*	10 min
Virkon® Aquatic 1 %	5 min
Virkon® Aquatic 2 %	2 min
IPA 50 %	10 min
IPA 80 %	5 min
Vinegar 20 %	10 min
Methylated spirits 40 %	10 min

*FAC=free available chlorine

These laboratory experimental results can be used to guide treatment and exposure periods required to achieve high mortality for juvenile *C. fluminea.* However, confirmatory testing revealed multiple instances (e.g., 2 % Janola® – 10 minutes exposure, 40 % IPA – 10 minutes exposure) where standard testing (with 30 organisms exposed) proved inaccurate compared to testing with 100 organisms. Therefore, we recommend adopting a conservative approach (i.e., increased dose and/or exposure periods) to increase the certainty of achieving 100 % mortality.

Further phases of research are recommended to explore other potential treatments (e.g., detergent) and optimise effective treatments for juvenile *C. fluminea* and other life stages. Determining how to achieve maintenance of target exposure levels, refining application methods, and evaluating the potential risks and off-target impacts of using hazardous or environmentally toxic treatments should also be considered. Copper and zinc treatments may demonstrate higher efficacy if lower concentrations of chelated compounds (e.g., in the form of citrates etc.) are used with prolonged exposures. This combination may reduce the protective closure response of the organisms evident throughout testing.

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Appendix A Standard and confirmatory testing physicochemical and FAC results

Table A-1: Summary of treatment physico-chemical and free available chlorine (FAC) measurements. nm= not measured, N/A = not applicable.

Treatment dose / concentration	Temperature °C	pH	Dissolved oxygen mg/L	Conductivity µs/cm	Free available Chlorine* (FAC) mg/L
Control – raw water	20	7.64	8.8	194	N/A
Water 42 °C	42	7.64	nm	194	N/A
Water 50 °C	50	7.64	nm	194	N/A
Water 55 °C	55	7.64	nm	194	N/A
Water 60 °C	60	7.64	nm	194	N/A
Water 70 °C	70	7.64	nm	194	N/A
Brine 100 ppt	20	nm	6.5	nm	N/A
Desiccation (drying)	20	N/A	N/A	N/A	N/A
Janola® 0.05 %	19	8.47	9.1	258	26/ nm
Janola® 0.1 %	19	9.03	9.1	331	77/ 72
Janola® 0.5 %	18.9	10.32	9.1	812	370/ 350
Janola® 1 %	19	10.77	9.2	1668	750/ 725
Janola® 2 %	18.9	11.01	9	3.13 ms/cm	1575/ 1450
Janola® 5 %	18.9	11.59	9.2	7.62 ms/cm	3550/ 2300
Salt-Away® 1 %	19	6.91	9.1	805	N/A
Salt-Away® 20 %	19.5	6.46	8.5	10.85 ms/cm	N/A
Salt-Away® 50 %	19.3	nm	8.1	15.84 ms/cm	N/A
Virkon® Aquatic 0.1 %	19.5	3.01	8.3	1160	N/A
Virkon® Aquatic 0.5 %	19.5	2.22	8.5	4.75 ms/cm	N/A
Virkon® Aquatic 1 %	18.7	1.8	9.2	8.8 ms/cm	N/A
Virkon® Aquatic 2 %	18.7	1.65	9.6	15.47 ms/cm	N/A
IPA 30 %	19.5	7.71	8.9	58.3	N/A

IPA 40 %	19.5	7.77	9	41.4	N/A
IPA 50 %	20	7.79	9.7	28.5	N/A
IPA 70 %	19	7.96	8.9	11.2	N/A
IPA 80 %	19	8.48	10.3	7.36	N/A
IPA 90 %	19	nm	10.1	3.6	N/A
Vinegar 5 %	20	3.15	8.8	401	N/A
Vinegar 15 %	20	2.81	8.4	620	N/A
Vinegar 20 %	20	2.7	8.3	547	N/A
Vinegar 30 %	20	2.57	8.3	853	N/A
Methylated spirits 30 %	19	8.09	8.9	69.9	N/A
Methylated spirits 40 %	19	8.04	8.7	63.8	N/A
Methylated spirits 50 %	19	8.03	8.6	37.3	N/A
Methylated spirits 80 %	19	nm	9.5	15.5	N/A
Methylated spirits 90 %	19	nm	8.1	9	N/A
6.25 mg/L Cu^{2+}	20	7.28	nm	nm	N/A
12.5 mg/L Cu^{2+}	20	7.63	nm	nm	N/A
25 mg/L Cu^{2+}	22.5	7.5	nm	nm	N/A
15 mg/L Zn^{2+}	18.9	6.95	9.1	238	N/A
50 mg/L Zn^{2+}	18.9	6.83	9.2	337	N/A
75 mg/L Zn^{2+}	18.9	6.86	9.3	388	N/A

* FAC at exposure start/ FAC at exposure end.

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Habitat suitability of Aotearoa New Zealand for the recently invaded gold clam (*Corbicula fluminea*)

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ABSTRACT

The gold clam (*Corbicula fluminea)* is a highly invasive freshwater mollusc, which was detected in Aotearoa New Zealand in 2023. Currently, *C. fluminea* has only been observed in the Waikato catchment, but there is significant concern it will spread across the country. There is an urgent need to identify suitable habitat for the species beyond the Waikato, given the high probability of spread. Here, we used a Maximum Entropy (MaxEnt) model to predict habitat suitability across Aotearoa for *C. fluminea*. The model was parametrised with 9,544 observations from across the species' native and invaded ranges and seven climate, environmental and habitat variables associated with the species' distribution. The highest risk area are mostly located in Te Ika-a-Māui (North Island), in particular, northern Waikato, Auckland, Northland, Bay of Plenty, Hawke's Bay and in Te Waipounamu (South Island) areas with the highest habitat suitability included Marlborough, North Canterbury and Christchurch. Our findings suggest there are many invadable areas beyond the Waikato and a strategy of containment and suppression of existing *C. fluminea* populations should now be a priority, given the difficulty of eradication once further spread has occurred and new populations are well established.

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Introduction

The rate of biological invasions has increased significantly with increased global trade and travel (Crespo et al. 2015: Black et al. 2021), allowing invasive species to overcome biogeographical barriers, which previously restricted their distribution (Darrigran 2002: Hulme 2009). In conjunction with this, climate change is acting as a secondary driver of shifting species distributions (Etherington et al. 2022). As regions experience fluctuations in their climatic trends, some areas become more suitable for invasive species, while concurrently less suitable for native species adapted to previous climatic regimes (Petitpierre et al. 2012: Lo Parrino et al. 2022). Preventing the initial spread of

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an invasive species as soon as possible after it has been detected, is the most effective management strategy in limiting the impact of an invader in a new territory (MPI 2023). This requires a quick response and an active, effective control programme (Leung et al. 2005: Petitpierre et al. 2012). To follow this strategy successfully with targeted control measures, areas of high invasion risk need to be identified.

Correlative environmental niche models (ENMs) are widely used to predict potential habitat suitability for species invading new areas (Di Cola et al. 2017; Kramer et al. 2017; Lake et al. 2020). Such models rely on the assumption that the realised niche of an invasive species is conserved between the native and invaded range (Petitpierre et al. 2012). However, niche conservatism is not guaranteed as a shift in the realised niche may occur due to adaptive evolution, because of changes in biotic interactions or changes in dispersal limitation (Broennimann et al. 2012; Torres et al. 2018; Bates and Bertelsmeier 2021). If a species conserves its realised niche, an ENM should correctly identify suitable habitat in the invaded range, and therefore, can be used to prioritise management actions based on the highest risk areas. Alternatively, if a species niche has shifted between the native and invaded ranges, there can be less confidence that the ENM will accurately predict habitat suitability. This is because the species may establish in environments not occupied in the native range, making it difficult to prioritise areas for management.

There are three commonly used metrics to describe patterns of niche shift: niche expansion, niche stability and niche unfilling (Petitpierre et al. 2012: Torres et al. 2018). Niche expansion describes a shift in the realised niche which expands past abiotic boundaries (or limits) observed in the native range. Niche stability is synonymous with niche overlap and measures the proportion of the niche that is conserved between the native and invaded range. Finally, niche unfilling represents the area of the native niche not being filled in the invaded niche (i.e. a reduction in the use of native niche space; Lo Parrino et al. 2022).

The 2023 discovery of the freshwater mollusc *Corbicula fluminea* (also known as the gold or Asian clam) in the Waikato River in Te Ika-a-Māui (the North Island) of Aotearoa New Zealand (hereafter Aotearoa), provides an example of a relatively well-documented invasion of a new land mass, at the very start of the invasion process (MPI 2023). The species is known worldwide for being one of the most ecologically and economically damaging freshwater invasive species and has invaded all major continents (except Antarctica; Crespo et al. 2015). No invaded countries have been able to eradicate the claim and, internationally the use of public messaging such as 'Check, Clean, Dry' campaigns to slow or control its spread has had a limited impact (Darrigran 2002; Lucy et al. 2012; Richardson 2020). However in Aotearoa, the 'Check, Clean, Dry' campaign has contributed to preventing the spread of didymo (*Didymosphenia geminata*) into Te Ika-a-Māui (Root and O'Reilly 2012). *C. fluminea* can survive extended periods out of water (Barbour et al. 2013; Crespo et al. 2015), so more extreme measures other than drying, such as thermal stress or chemical exposure may be required to sterilise gear and prevent spread (Barbour et al. 2013; Coughlan 2019).

The long-term impact of *C. fluminea* on freshwater ecosystems in Aotearoa is still to be determined and will ultimately be dictated by how effective management efforts are at restricting its distribution and protecting native ecosystems from new incursions. Internationally, *C. fluminea* has damaged infrastructure such as by biofouling water treatment systems and power plants and 'ecosystem-engineered' new habitats by dominating resident bivalve assemblages in terms of numbers and biomass and by their presence effectively altering the type of substrate available for benthic macroinvertebrates (Phelps 1994;

Darrigran 2002; Lucy et al. 2012; Barbour et al. 2013). Of particular concern in Aotearoa is the potential for *C. fluminea* to outcompete native freshwater mussels such as Kākahi (*Echyridella spp.*), which are also taonga ('treasured') species (MPI 2023). Given *C. fluminea* has a faster growth rate than Kākahi, a higher reproductive output, can reproduce asexually, has broader environmental tolerances and can exhibit mass 'die-offs' releasing sufficient ammonia to kill some species of unionid mussels (Cherry et al. 2005; Coughlan 2019; Robb-Chavez et al. 2023), a complete species replacement is feasible. Preventing the establishment of an invasive species requires a quick response and an active control programme that limits spread past the introduction site (Leung et al. 2005; Petitpierre et al. 2012). To do so successfully, with targeted control measures, areas of high invasion risk should be identified.

C. fluminea has never been successfully eradicated from any country it has invaded and given the low probability of eradication in Aotearoa and the potential negative effects of *C. fluminea* (MPI 2023), there is an urgent need to understand which parts of the country are most vulnerable to colonisation. Identifying invasion hotspots will allow iwi (Indigenous tribes of Aotearoa), local government and conservation groups to proactively manage *C. fluminea* and vulnerable endemic species. Therefore, the main objective of our study was to assess the habitat suitability of Aotearoa for *C. fluminea* and highlight high-risk freshwater habitats. We aimed to (i) quantify the niche of *C. fluminea* across its native and invaded range outside of Aotearoa and (ii) use an ENM to identify areas of potentially suitable habitat across Aotearoa.

Methods

Species data

Global occurrence records for *C. fluminea* were downloaded from the Global Biodiversity Information Facility (GBIF; GBIF.org [16 November 2023]; https//doi.org/10.15468/dl.m6696c). We discarded records collected before 1970 to ensure a consistent temporal starting point of occurrence and environmental data whilst balancing the loss of observation records. Presence points located > 1 km from waterbodies were discarded, and those points within 1 km of waterbodies were moved to the nearest waterbody (Lo Parrino et al. 2022). We followed GBIF data cleaning protocols (Torres et al. 2018; Etherington et al. 2022; Rodriguez et al. 2023) and removed any records that were located within 1 km of country centroids, within 10 km of the GBIF headquarters, had coordinate uncertainty of >1 km or were located in the ocean. We thinned presence points to match the resolution of environmental data (1 km). Fossil and captive records were removed. The final dataset consisted of 24,536 observations, 427 in the native range and 24,109 in the invaded range (Figure 1).

Environmental data

Global environmental data were downloaded at 30 arc-seconds (~1 km at the Equator) resolution from the EarthEnv freshwater environmental database (Hijmans et al. 2005; Domisch et al. 2015). The database contains near-global, spatially continuous, freshwater-specific, environmental variables in a standardised 1 km grid (Domisch

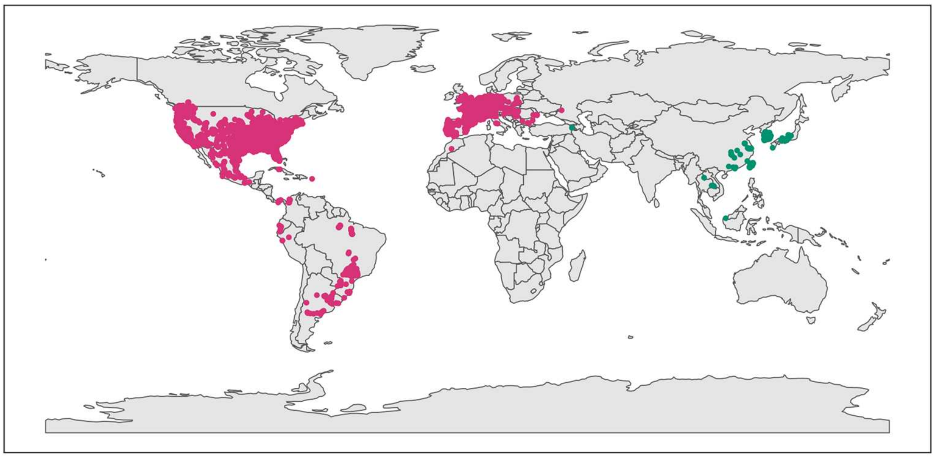

Figure 1. Summary of *C. fluminea* occurrence records after cleaning. The pink points are in the invaded range and the green points are in the native range. The native range was delineated following Torres et al. (2018) who used the whole of Asia as the native area for *C. fluminea*.

et al. 2015). Eight environmental variables were selected based on their known importance as determinants of *C. fluminea* distribution, or as limiting key life stages, these were the maximum temperature of the warmest month, minimum temperature of the coldest month, mean annual temperature, slope, per cent sand content of the substrate, soil pH dissolved in water, upstream catchment area and elevation (Table 1). Available

Table 1. Summary of the eight environmental variables used to explain the distribution of *Corbicula fluminea*.

Environmental variable	Explanation	*C. fluminea* tolerance	Tolerance source	Data source
Temp_WM	Maximum temperature of the warmest month (°C)	Maximum tolerance of 37°C	Lucy et al. (2012)	Brun et al. (2022)
Temp_CM	Minimum temperature of the coldest month (°C)	Minimum tolerance 0–2°C although may survive freezing	Lucy et al. (2012), Robb-Chavez et al. (2022)	Brun et al. (2022)
Temp_mean	Mean annual temperature (°C)	Requires waters 15°C or warmer to reproduce	Lucy et al. (2012)	Brun et al. (2022)
Slope	Mean slope	Prefers low gradients	Robb-Chavez et al. (2022)	Amatulli et al. (2018)
Sand	Mean sand content (%) of substrate	Prefers well-oxygenated (sandy) substrate	Darrigran (2002)	Hengl et al. (2014)
pH	Mean soil pH dissolved in water	Lower tolerance of 5.6	Lucy et al. (2012)	Hengl et al. (2014)
Area	Number of upstream cells	Likely to be found in large, slow-flowing bodies of water	Paschoal et al. (2015)	Lehner et al. (2008)
Elevation	Minimum elevation (m asl)	Likely to be found at lower elevations	Gama et al. (2016), Lehner et al. (2008)	Lehner et al. (2008)

The three temperature variables were sourced from the CHELSA database (https://chelsa-climate.org; Karger et al. 2017). The remaining five variables were downloaded from the EarthENV freshwater ecosystem, and topography (slope) databases (https//www.earthenv.org/; Domisch et al. 2015). Mean annual temperature was used for niche analysis, but not in the MaxEnt model.

calcium is important for any bivalve's development, and therefore the distribution of *C. fluminea*, but global data for this variable were not available. Although a lower calcium limit of 3 mg l^{-1} has been reported (Lucy et al. 2012), the calcium requirements for *C. fluminea* are still poorly understood (McMahon 2002; Bollens et al. 2021) and the clam is thriving in high densities in ponds as low as 3.1 mg l^{-1} (Smagula et al. 2018). This level is typically lower than those present in many waterbodies in Aotearoa (Close and Davies-Colley 1990) and therefore, we do not think the omission of this predictor significantly affected our results. Nonetheless, we do acknowledge that the inclusion of calcium as a variable would have been preferable.

Niche analysis

To compare the niche of *C. fluminea* in its native and invaded range, we used the Centroid shift, Overlap, Unfilling and Expansion (COUE) framework (Broennimann et al. 2012; Rodriguez et al. 2023). Environmental values at all presence locations were extracted from the eight environmental layers. Additionally, environmental values at 10,000 random background locations in both the native and invaded range were sampled (Hill et al. 201720176]; Lo Parrino et al. 2022). The geographic background is the study area limited to the available areas that the species could colonise. To delimit the geographic background for niche comparison of freshwater species it is common to use freshwater ecoregions (Abell et al. 2008) that overlap with the nativeand invaded distributions (Torres et al. 2018; Parrino et al. 2022; Rodriguez et al. 2023). There was not a consensus in the literature when describing *C. fluminea's* native range, with some sources suggesting the species is native to Asia, Africa and Australia, while others suggest it is only native to Asia or Southeast Asia (Lucy et al. 2012; Torres et al. 2018). Given this conflicting information, we tested three potential native backgrounds. The first was a buffered (200 km) convex hull around presence points located in Southeast Asia (SM Figure 1). The second background comprised the freshwater ecoregions (Abell et al. 2008) that intersected with the buffer (SM Figure 2). The third background tested was constructed using the same strategy as Torres et al. (2018) and covered all of Asia (SM Figure 3).

Initially, the niche of *C. fluminea* was visualised in environmental space, via a principal component analysis (PCA). A probability density function (PDF) was constructed using a smoothed kernel estimator around scores from the PCA for the environment occupied by the species and the geographic background (Broennimann et al. 2012). The niche changes of *C. fluminea* were described using the metrics niche overlap (Schoner's D), niche stability, niche expansion and niche unfilling. All metrics vary between 0 and 1, where values close to 1 indicate a high overlap, stability, expansion and unfilling. We conducted niche similarity and equivalence tests comparing overlap between the native and introduced niches to 1000 randomly generated distributions (Warren et al. 2008). A significant niche similarity test implies that *C. fluminea* occupies environments in the native and invaded range that are more similar than would be expected by chance. However, a significant equivalency test suggests that the overlap between native and invaded niches is higher than expected under randomness (Warren et al. 2008). We included all environments (non-analogous and analogous environments (Bates and Bertelsmeier 2021)) and retained all presence records when calculating niche metrics. However, it is common to remove marginal climate and observation data, and this can influence metric scores (Bates and Bertelsmeier 2021). Therefore, we conducted a sensitivity analysis on the effect of removing marginal environments and presence observations (Petitpierre et al. 2012; Torres et al. 2018). We recalculated niche metrics after removing the 5, 10, 15, 20 and 25% most marginal environments and species observations (SM Figure 4).

Habitat suitability modelling

To determine habitat suitability for *C. fluminea* in Aotearoa, we used a maximum entropy (MaxEnt) model (Phillips et al. 2006). MaxEnt is a presence-background approach based on an inhomogeneous Poisson process specifically designed for presence-only data (Phillips et al. 2006). We used MaxEnt due to its superior performance over other ENM algorithms that use presence-only data and generally high performance (Valavi et al., 2022). The same environmental parameters used in the niche metric modelling were used for the MaxEnt model, except for average annual temperature, which was removed because it was highly correlated with the minimum temperature of the coldest month.

A calibration area was delimited by a 200 km buffer around presence locations, further constrained by catchment boundaries. Species presences were environmentally filtered, which reduces spatial autocorrelation and environmental redundancy (Rodriguez et al. 2023). When filtering presences, observations must be divided into bins, with the choice of the number of bins having a large effect on the number of points retained. Therefore, we reran the function with 2, 5, 10, 15, 20, 25, 50 and 100 bins and kept the bin number that (i) reduced the mean spatial autocorrelation of predictors, as indicated by Moran's I and (ii) allowed us to keep the maximum number of presences. In this case, using 30 bins resulted in the lowest Moran's I and left 9544 presences (SM Figure 5).

As the model was being applied to a region outside the range of current species observations, we used a spatial block partition to split the data into training and testing groups (Velazco et al. 2022; Rodriguez et al. 2023). The presence data were spatially partitioned into four groups, after testing 30 grid sizes (Velazco et al. 2022). The optimum spatial extent for a grid cell was selected based on three parameters: minimising spatial autocorrelation, high similarity of environmental observations and spreading species observations across blocks (Velazco et al. 2022). The spatial partitions were then used to generate a stratified sample of background points, further weighted by a bias layer. The number of background points was set to equal the number of presences found in each partition (9544 in total). Our bias layer was constructed using a target-group background approach, where known locations of species with similar life history strategies were used to constrain background sampling (Phillips et al. 2006). In this case, we used all records of bivalves from GBIF (doi:10.15468/dl.ekq88a), using the same data cleaning workflow outlined for *C. fluminea*. These data were then converted into a continuous surface, via 2D kernel density estimation, which represents sampling effort (Barber et al. 2022).

We tuned the model using a variety of hyper-parameter settings. We tested regularisation multiplier settings of 0.5, 1, 2, 3 or 4 and feature class settings of linear, hinge, quadratic and their interactions. We then selected the hyper-parameter combination that returned the highest Continuous Boyce Index (CBI). The final model had the regularisation multiplier set to 3 and feature class 'lhq'. MaxEnt results of habitat suitability are presented on the clog-log scale, where values range between 0 (low habitat suitability) and 1 (high habitat suitability).

Model discrimination was assessed using two indicators, the CBI and the area under the receiver operating characteristic curve (AUC), where values range from 0 to 1, with a value of 0.5 indicating no better than random predictive ability and a score of 1 indicating perfect prediction. The CBI is favoured in studies that use presence-only data, where values scale from −1 to 1, with higher values indicating better performance. Finally, we quantified the degree of extrapolation in environmental space between the training and projection data, using the Shape metric (Velazco et al. 2023). Shape was calculated using the multivariate distance from each projected point to the nearest training data point, in environmental space. If a given projection datum has a corresponding Shape of 100, it is 100 times further away from the nearest training datum than the averaged Mahalanobis distance between training data points and the centroid of the training data (the dispersion factor Velazco et al. 2022).

Software

All analysis was carried out in R v 4.3.2 (R Core Team 2023), niche metrics were calculated using the ecospat v 4.0.0 package (Broennimann et al. 2023), MaxEnt models were run using the flexsdm v 1.3.4 package (Velazco et al. 2022) and the tidyverse v 2.0.0 meta-package (Wickham et al. 2019) was used for data manipulation and visualisation. Simple feature objects were created and modified using the sf v 1.0-15 package (Pebesma 2018: Pebesma and Bivand 2023) and raster files were manipulated using terra v 1.7-65 (Hijmans et al. 2022).

Results

Niche analysis

To address aim one, we quantified the niche of *C. fluminea* across its native and invaded range outside of Aotearoa. We found that the eight predictor variables selected for this study explained 56% of the variation in our data, with the first PCA axis explaining 39% and the second PCA axis explaining 17% (Figure 2). The first PCA axis (PC1) described an elevational and temperature gradient, where negative values were associated with low elevation, low gradient warmer sites and positive values were associated with high elevation, high gradient, cooler sites. The second PCA axis (PC2) described a gradient of substrate and pH, where negative values were associated with less sand content and lower pH, while positive values had higher sand content and lower pH. The ordination revealed that temperature and elevation variables along PC1 are the main drivers of variation within the native and invaded environmental space with higher densities associated with warmer, low elevation, low gradient conditions (Figures 2 and 3). Most niche expansions occurred in environments that contained relatively sandier, larger catchments, with higher pH. Temperature and elevation conditions where niche

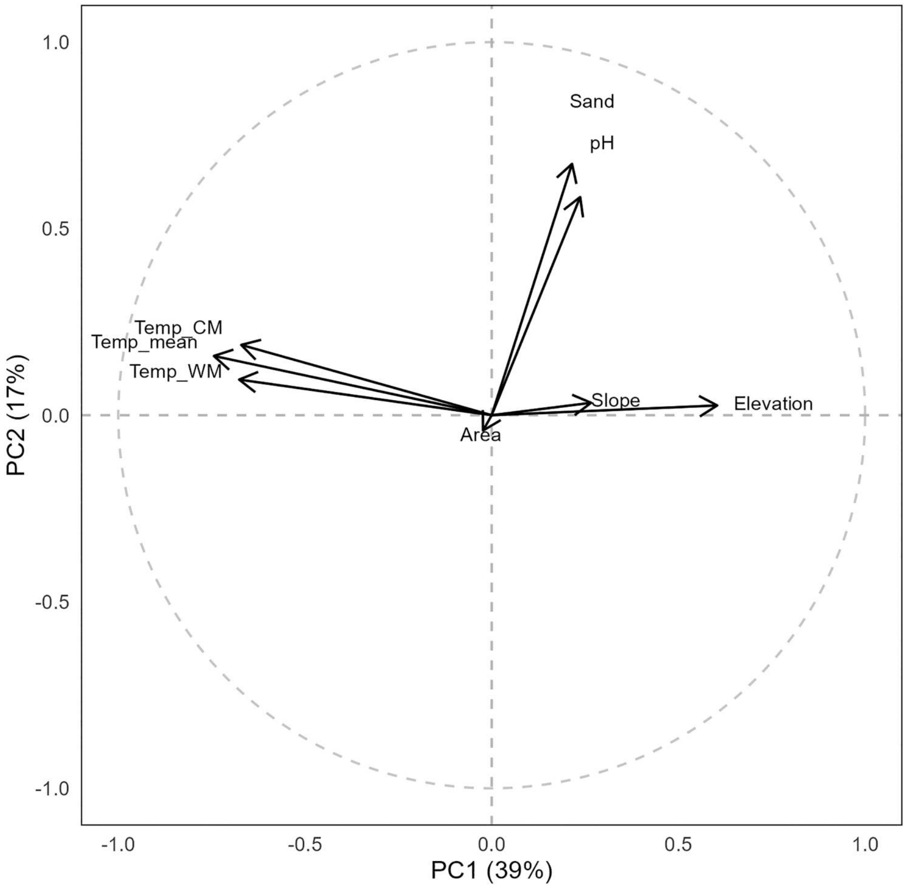

Figure 2. Principal component analysis of the eight environmental parameters used to describe the niche of *Corbicula fluminea*. The first two axes explain 56% of the overall variation.

expansion occurred were similar to those where niche stability was observed, indicating *C. fluminea* has exploited its full temperature niche in both the native and invaded ranges (Figures 2 and 3). Schoener's D was 0.43, indicating a high degree of overlap between native and invaded niches (compared to other studies). Niche Stability was high (0.76),indicating that 76% of the niche space occupied remained stable across the two ranges. The main direction of shift in the occupation of environmental space was driven by expansion (0.24), with low levels of unfilling (0.005), indicating most of the environmental conditions in the native range have been occupied in the invaded range (Figure 3). Using different definitions of the native range had little effect on niche overlap metric scores (SM Figure 6 and SM Figure 7).

The niche equivalence test was not significant ($p = 1$), indicating the invaded and native niches are not more equivalent than expected when compared with the random overlaps generated for the null model. The niche similarity test was significant ($p = 0.02$) suggesting the native and invaded niches are more similar than expected by chance.

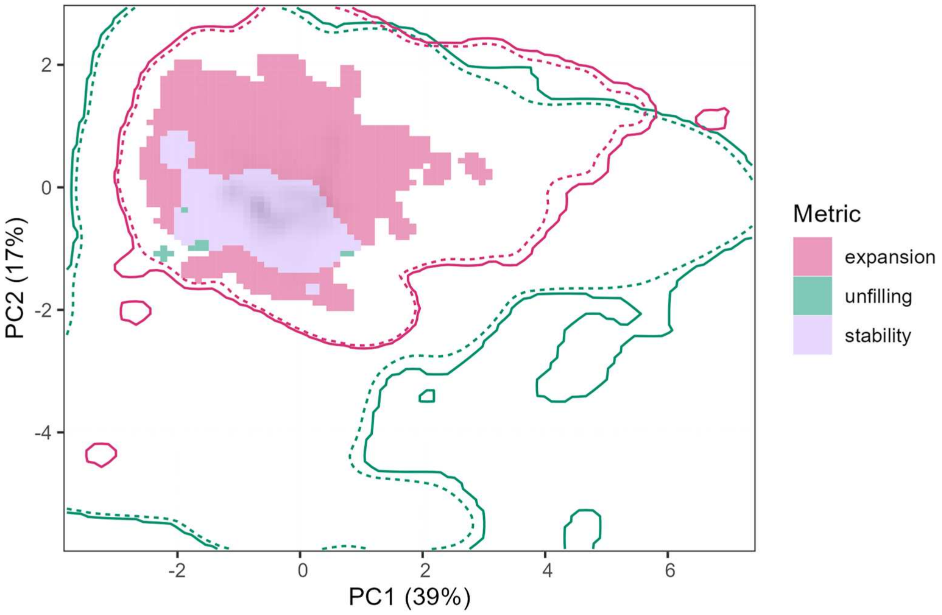

Figure 3. Overlap between the native and invaded niches of *C. fluminea* in multivariate environmental space. Niche stability (0.76) represents the proportion of climatic space that is occupied in both native and invaded ranges. The shaded area represents the density of occurrence points in the invaded range. Niche expansion (0.24) represents the occupation of environmental space that is unique in the invaded range. Niche unfilling (0.005) represents a portion of climatic space occupied in the native range that has not been filled in the invaded range.

Habitat suitability modelling

To address aim two, we used a MaxEnt model to identify areas of potentially suitable habitat across Aotearoa. The model performed well and had a mean Boyce index of 0.99 (SD 0.001) and an AUC score of 0.88 (SD = 0.01). Habitat suitability ranged from 0 to 0.55, with higher habitat suitability in Te Ika-a-Māui and lower suitability in Te Waipounamu (Figure 4A). Constraining projections by Shape showed the central part of Te Ika-a-Māui and western Te Waipounamu contained non-analogous environments compared to training data, and therefore confidence of predictions in these areas is less certain (Figure 4B–C, Figure 5). We constrained the projection to only show locations with higher habitat suitability than Bob's Landing (0.33), the location of the first detection of *C. fluminea* in Aotearoa and the location of a thriving, well-established population (Figure 4D; MPI 2023). Areas with the highest habitat suitability and where model confidence was greatest, included much of northern Waikato, Auckland, Northland, Bay of Plenty, Hawke's Bay and Gisborne (Figure 4D). In Te Waipounamu, areas with the highest habitat suitability included Marlborough, North Canterbury and Christchurch (Figure 4D). Important drivers of habitat suitability were temperature, elevation and pH. Other environmental predictors had little effect on habitat suitability, which was positively associated with warmer temperatures in both the coldest and warmest months, lower elevation sites and pH above 4.5. (Figure 6).

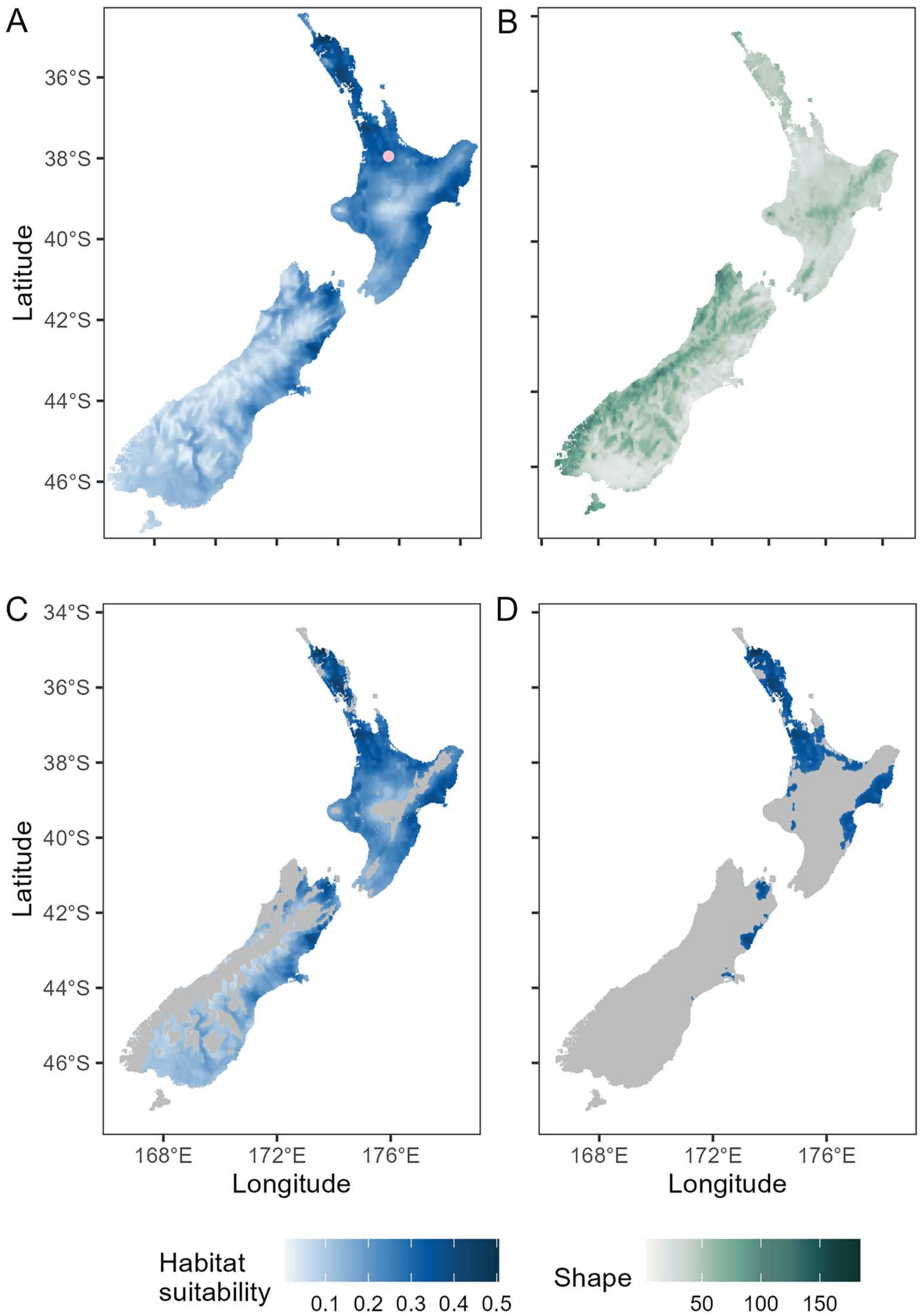

Figure 4. A, Habitat suitability of Aotearoa, New Zealand for *C. fluminea*, with Bob's landing marked in pink. **B,** Shape metric, darker greens represent environmental conditions increasingly dissimilar to conditions in the training dataset. **C,** Habitat suitability of Aotearoa, New Zealand for *C. fluminea*, where areas with Shape > 50 removed. **D,** Habitat suitability of Aotearoa, New Zealand for *C. fluminea,* showing all areas that have higher habitat suitability than Bob's Landing, the location where the first population was discovered.

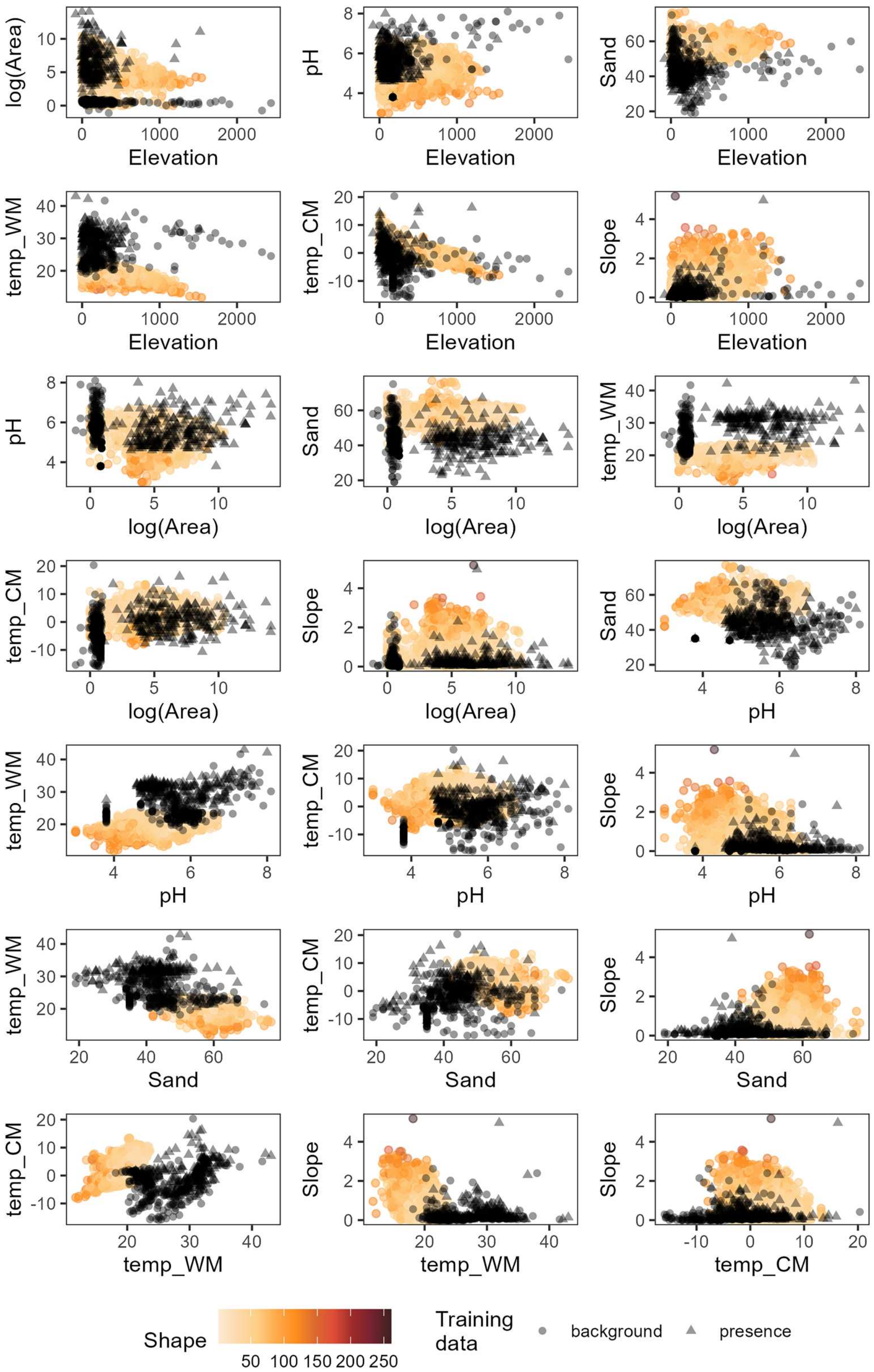

Figure 5. Distances between the training data (black points) and projected area (Aotearoa, coloured points) in environmental space as defined by the Shape metric.

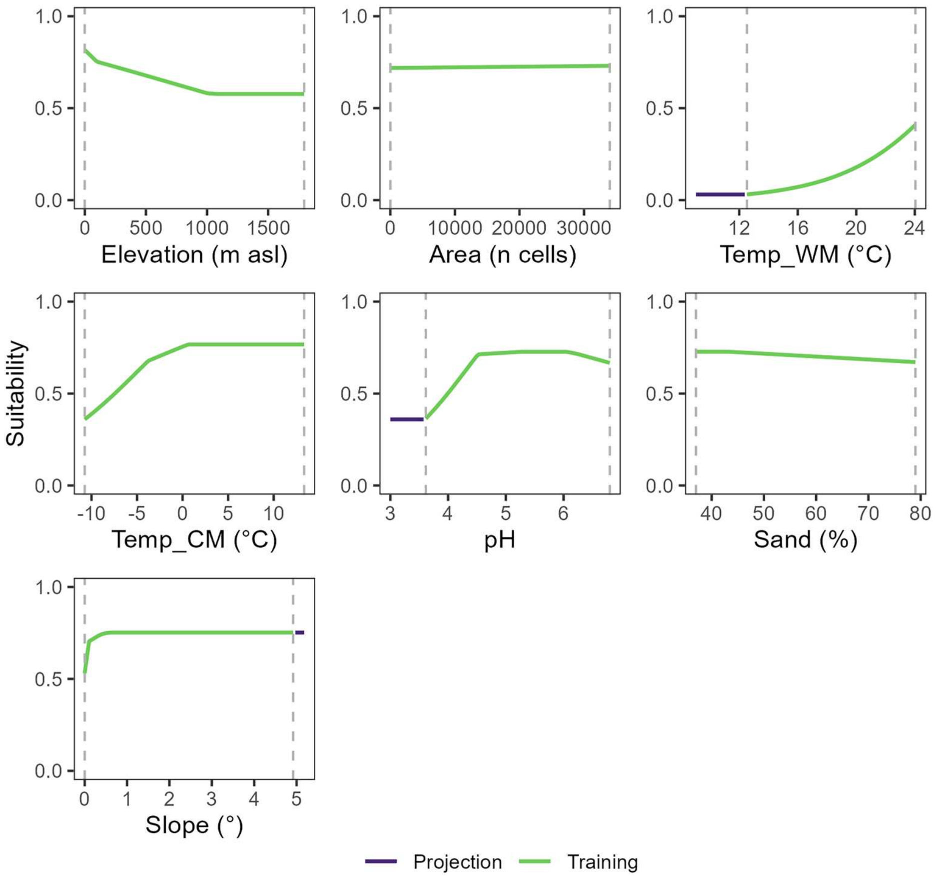

Figure 6. Partial dependence plots for each of the seven environmental predictors were used to predict the distribution of *C. fluminea* across Aotearoa New Zealand.

Discussion

C. fluminea is a freshwater clam regarded as one of the most prolific freshwater invaders worldwide (Barbour et al. 2013; Robb-Chavez et al. 2023). The high reproductive potential, fast growth, broad environmental tolerances and filtering capacity of the clam make it a successful and aggressive invader of freshwater and brackish ecosystems (Darrigran 2002; Crespo et al. 2015; Richardson 2020; TAG report 2023). The discovery of this species in the Waikato River therefore prompted a response from Waikato-Tainui, the Ministry of Primary Industries (MPI) and the Department of Conservation (DOC). River surveys, a controlled area notice, cancellation of recreational events and new public messaging campaigns represent some of the management strategies implemented since the clam was first discovered (TAG report 2023).

The comparison of the realised niche between the native background (Asia) and the invaded backgrounds indicated that the species largely conserves its niche after invading a new range. This differs from a prior study indicating a slightly higher degree of niche expansion (0.13) and low overlap (Schoner's D = 0.19; Torres et al. 2018). The difference in results is likely driven by parameter selection and the number of occurrence points in the native range (we had 427, whereas Torres et al. (2018) had 16; Parrino et al. 2023). Additionally, as this study was focused on an individual species, we selected environmental predictors known to be important for its specific distribution, whereas Torres et al. (2018) modelled many species and used general temperature, solar radiation and precipitation variables.

Habitat suitability and environmental drivers

Habitat suitability was higher in Te Ika-a-Māui than in Te Waipounamu, in particular, northern Waikato, Auckland, Northland, Bay of Plenty, Hawke's Bay and Gisborne and the coastal areas of Te Ika-a-Māui have the highest habitat suitability. In Te Waipounamu areas with the highest habitat suitability included Marlborough, North Canterbury and Christchurch. The key environmental parameters driving *C. fluminea's* distribution were the pH of soil water and temperature variables (maximum temperature of the warmest month and minimum temperature of the coldest month). Gold clams can withstand temperatures as low as 0°C and require temperatures above 15°C to spawn (Lucy et al. 2012). Much of Aotearoa meets this requirement for large parts of the year, with temperature likely limiting the distribution in high-elevation parts of the country only (Bates and Bertelsmeier 2021: Robb-Chavez et al. 2023). pH of soil water was a significant driver of habitat suitability. This is common in bivalves, or other calcifying organisms. The model depicts a threshold-like response to decreasing pH, where occurrences drop off significantly at pH values of about 4.1 (pH). Lucy et al. (2012) point to a lower tolerance of 5.6 (pH) where populations in these conditions have visible shell deterioration. Lower pH is more likely a limiting factor in waterbodies with low available calcium. Although available calcium could not be included in this study, as it is not available on a global scale, there is evidence suggesting most waterbodies in Aotearoa are above the lower threshold exhibited by the clam (Close and Davies-Colley 1990; Lucy et al. 2012).

These predictions are based on past climatic and edaphic conditions that do not account for future climate change. Warmer conditions will promote spawning, enhance population densities and allow the spread of *C. fluminea* into areas marked less suitable by this study (Lo Parrino et al. 2022). The regions becoming increasingly suitable will be most prevalent in Te Waipounamu. It is likely that, following the current climate trajectory, much of Te Waipounamu will become more suitable than is currently being indicated by this study. The implications of this may be a range shift as the species seek cooler temperatures or more likely a range expansion as the clam comes to find areas it can now invade.

Study limitations

The data used for this study were available at a 1 km resolution (Domisch et al. 2015; Amatulli et al. 2018). Freshwater ecosystems are full of intricacies and microclimates, some of which will be lost at this spatial resolution (Lo Parrino et al. 2022). Fine-scale variability is, therefore, unaccounted for in this study and has likely simplified the results. The environmental parameters used were near-globally available. This criterion meant some parameters had to be excluded from the study and were ultimately not included in the consideration of habitat suitability. While we believe that the predictors used here capture the main drivers of *C. fluminea's* distribution others may influence distribution patterns. An obvious omission is available calcium. Bivalves require calcium to build their shells and it is, therefore, a key driver of distribution (Gama et al. 2016). A lower limit of 3 mg^{-1} presented by Lucy et al. 2012 is below the recorded level within most waterbodies in Aotearoa (Close and Davies-Colley 1990). Therefore, the exclusion of this parameter may not influence the results greatly. Other environmental factors, such as available oxygen, available organic matter and macrophyte, cover (%) may impact habitat suitability (Gama et al. 2016).

Biological interactions can drive the distribution of species, these were not modelled here. Aotearoa has a different freshwater community compared to other invaded areas (Drinan et al. 2020). The low freshwater mollusc diversity in Aotearoa will likely keep competition between species from limiting the spread of *C. fluminea* (Moore 2020). The dominant sources of predation may come from other introduced species, such as catfish or waterfowl (Robinson and Wellborn 1988; Sazima and D'angelo 2013). The implications of these novel interactions on the distribution and spread of *C. fluminea* are not well understood. Finally, food availability will also shape distributional and abundance patterns, it is possible some water bodies will have such low productivity that they will not be able to support *C. fluminea* (Rivera-Estay et al. 2024). However, food availability is unlikely to be a limiting factor in the majority of waterbodies.

Dispersal, containment, and management recommendations

C. fluminea was first introduced to Europe, and North America in the 1970s and spread quickly (Darrigran 2002; Lucy et al. 2012). The natural dispersal of *C. fluminea* is focused downstream (juvenile settlement) and although there is a capacity to move upstream mature individuals this process is slow (Lucy et al. 2012). However, dispersal is accelerated by vectors of transport such as boat hulls or fishing equipment (Lucy et al. 2012; Crespo et al. 2015; TAG report 2023). Another form of transport, though not well understood, is by other organisms such as waterfowl and migratory fishes (Gatlin et al. 2013; Crespo et al. 2015). *C. fluminea* has an international reputation for being hard to contain and nearly impossible to eradicate (Barbour et al. 2013; Coughlan 2019). Once populations have established past the initial site of introduction it becomes increasingly difficult to eradicate the species (Darrigran 2002; Lucy et al. 2012; Richardson 2020). Due to the small size, environmental tolerances, and ability to reproduce asexually, it is also difficult to prevent spread into new waterbodies (Coughlan 2019; Robb-Chavez et al. 2023). Resources should be focused on suppressing populations and ultimately containing the species in the Waikato catchment.

Conclusion

We found evidence for niche conservatism in *C. fluminea*, across the native and invaded ranges. Therefore using a model such as MaxEnt should perform relatively well when predicting the habitat suitability of currently uninvaded areas. Our findings indicate *C. fluminea* likely conserves its niche between native and invaded ranges. This niche conservatism suggests we can have some confidence in habitat suitability modelling results when projecting into uninhabited space (much of Aotearoa). The areas of high risk are mostly located in Te Ika-a-Māui, in particular northern Waikato, Auckland, Northland, the Te Arawa Lakes area of Bay of Plenty and the coastal areas of Te Ika-a-Māui. In Te Waipounamu areas with the highest habitat suitability included Marlborough, North Canterbury and Christchurch. Given the high levels of habitat suitability in areas around the Waikato River, we suggest restricting the spread of *C. fluminea* to this single catchment should be a top priority.

Contribution statement

RS and FL conceived the study, and RS completed the analysis of the data and wrote the first draft of the manuscript. All authors contributed to reviewing and editing the manuscript.

Data availability statement

Analysis performed on openly available data https//doi.org/10.15468/dl.m6696c.

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Disclosure statement

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1 Executive Summary

During five Technical Advisory Group (TAG) meetings on different topics, several important themes were evident regardless of the topic of the meeting.

- *Corbicula* has never been successfully eradicated elsewhere in its invaded range. It is extremely unlikely that it is eradicable in the Waikato Catchment, however there are some options that could be effective in containing and suppressing *Corbicula* populations to keep long term eradication on the table.
- This could involve enforced movement controls to aimed at containing *Corbicula* within its current distribution – encouraging best biosecurity practices, especially Check, Clean, Dry messaging.
- Testing combinations of established tools to understand synergistic effects in a structured manner is strongly recommended. Investigation of new tools for control of *Corbicula* in the known infested area of the Waikato River is also important.
- Any action taken to reduce *Corbicula* abundance will reduce populations and decrease propagule pressure, lowering the likelihood of spread outside of the Waikato.
- New surveillance tools should be developed and trialled to maintain wide ranging surveillance (across space and time), to detect any new populations early enough to attempt site-specific elimination immediately upon discovery. Environmental DNA (eDNA) is likely an important tool.
- A different suite of tools is available for managing impacts in an enclosed infrastructure environment.
- It is important for facilities and companies to start developing their own context-specific Standard Operating Procedures (SOPs) to mitigate potential impacts of *Corbicula*. Infrastructure assessment should evaluate whether any retrofitting of equipment is required. So far impacts on infrastructure are not significant but being prepared will help reduce any worse future impacts that may result if the population of *Corbicula* grows, and further range expansion occurs.
- Messaging to the public and industry regarding actions and behaviours that reduce the likelihood of *Corbicula* spread is very important as part of a long-term management strategy.
- Supporting kaitiaki, water sports clubs, anglers and other user groups to encourage and promote good biosecurity behaviour, and to develop specific messaging is a powerful approach.
- There are tools and treatments available to maintain culturally significant practices such as elver transfers in a biosecure manner, but these should be tested before the next transfer event.
- Translocating kākahi or other vulnerable native species (“arking” them) into long term quarantine or away from *Corbicula* invaded areas should be considered on a case-by-case basis. In the early stages of *Corbicula* suppression there are likely to be interim measures that are less complex (*e.g.* identifying suitable destination sites and shifting kākahi downstream from control areas). In the interim, developing methods and SOPs to clean and/or purge them of *Corbicula* can be worked on if research demonstrates purging is necessary.

2 Background to the Biosecurity Response

Initial events leading to the response being activated

0n 01 May 2023, BNZ was notified of the potential presence of *Corbicula fluminea* (hereafter referred to as *Corbicula*) in the Waikato River at Bob's Landing. The notification came from two researchers undertaking ecology field work in the area on 19th April 2023, where they found 10 empty shells. They shared images of the findings with two other scientists who suggested the shells may be from be one of two invasive species within the *Corbicula* genus.

On 2 May 2023, one of the researchers visited Bob's Landing again and collected live samples. This indicated a potential breeding population. On the 5th of May 2023, the species was confirmed as a species form the genus *Corbicula*. As the taxonomy of *Corbicula* is unresolved and following overseas convention and the fact that no other species in this genus is established in New Zealand it was agreed to name this species *Corbicula fluminea*.

Corbicula has a high reproductive potential, and a single individual can produce 400 juveniles a day under favourable conditions, with greater than 70,000 juveniles being produced per annum. The presence of the species could have significant potential impacts on the native ecosystem within the Waikato River and Lake Taupo, as well as further in Aotearoa New Zealand if it spreads.

Organisms in the *Corbicula* genus are known to cause serious issues for human activities, including blockage of water channels, factory infrastructure, irrigation pipes, storm water infrastructure, water treatment facilities and power stations.

The Waikato River is 452km long and includes Lake Taupo, a 616 km^2 waterbody. This is a substantial area of potential habitat suitable for *Corbicula* to establish.

The Waikato River has eight hydro dams along its length with numerous major water extractors and there is a significant risk that heavy infestation of *Corbicula* in the Waikato River could disrupt these operations.

There are currently no known effective treatment tools available to eradicate *Corbicula* populations, although there are population suppression tools available. Any suppression tool used to detrimentally impact *Corbicula* will also likely detrimentally impact native fauna in the Waikato.

See the Rapid Risk Assessment for further information.

3 Purpose of the Technical Advisory Group

Biosecurity New Zealand (BNZ) convened a Technical Advisory Group (TAG) made up of national and international scientists with extensive experience specifically in freshwater invasion ecology, mollusc control and specific experience with *Corbicula.* In addition, representatives from the iwi groups in the Waikato region were invited to share their important knowledge of place and perspectives.

The TAG was convened early in the biosecurity response before specific questions were identified for the TAG to answer. As such, a small Pre-TAG meeting was held with three local scientists to determine key issues that could be addressed by a TAG.

Based on information from this Pre-TAG, concerns expressed by iwi or stakeholders and work happening within the biosecurity response, five broad topics were identified as TAG meeting subjects. Due to the large membership of the TAG, not all participants attended all of the five meetings.

3.1 TAG membership

Complete TAG membership was the list of people as shown below, of which a subset was present at each meeting.

Name	Organisation	Area of expertise
Tracey Burton	Land Information New Zealand	Freshwater ecology
Adam Daniel	Fish and Game New Zealand	Freshwater ecology, Fish & Game Freshwater Invasive Species Coordinator
Sue Clearwater	Department of Conservation	Aquatic Toxicology, Freshwater ecology
Ian Duggan	University of Waikato	Biological invasion vectors and pathways
Calum MacNeil	Cawthron Institute	Freshwater and invasion ecology, environmental protection
Jaimie Dick	Queen's University Belfast	*Corbicula* management, invasion ecology, impacts of invasive species
Neil E. Coughlan	University College Cork	*Corbicula* management, freshwater ecology and control of invasive aquatic organisms
Mark Fenwick	National Institute of Water and Atmospheric Research	Freshwater and marine biology, ecology and genetics, kākahi taxonomics Mātauranga at place
Deborah Hofstra	National Institute of Water and Atmospheric Research	Freshwater biology, ecology and biosecurity
Frances Lucy	Atlantic Institute of Technology - Sligo	Aquatic Invasive Species, Fisheries Science and water quality

3.2 TAG subjects

3.2.1 Pre-TAG meeting

The main objective of this meeting was to understand how to best make use of a broad forum of experts to gain valuable information for the *Corbicula* response.

It was thought that learning from the experience of experts in a country where a *Corbicula* incursion had occurred to understand their "lessons learned" - and based on this, what the key messages would be to Aotearoa New Zealand regarding what should be done (or not), how to do it and how best to approach an incursion of *Corbicula fluminea*.

Other key discussion points from the pre-TAG were;

- The consensus was that it is highly unlikely that *Corbicula* will be eradicated from the Waikato River system, and containment would be a difficult but worthwhile. However, site-specific elimination of new populations may be possible if detected early enough. Therefore, site-specific elimination and catchment-level suppression could be a long-term goal.
- Tools and treatments that currently exist for controlling *Corbicula* are non-specific and likely to have significant impacts on non-target species. However, some tools and treatments are worth considering but require testing and further development in Aotearoa New Zealand. The consensus opinion was that visual surveillance was the most effective tool for detection of *Corbicula* for delimiting its distribution, although it was acknowledged that there is a possibility of missing populations given the narrow depth profile that it is possible to cover (currently wadable depths). Similarly, eDNA was discussed as a tool that needs development and validation work before becoming an effective surveillance tool.
- Delimiting existing populations and ongoing surveillance in other unconnected freshwater bodies is important, to 1) understand the species distribution and 2) to ensure early detection of any newly established populations.
- Actions to ensure preservation of taonga species could be necessary. *Corbicula* is a highly effective ecosystem engineer and the ecological niche it will occupy in Aotearoa New Zealand may have less interspecific competition from native species than in other invaded regions overseas, therefore the impacts on native species may be greater than in other invaded regions.

3.2.2 TAG #1 – International experience

Key Questions;

- What was the experience in your country with a *Corbicula* incursion?
- What actions were taken, and did they work?
- Knowing what you do now, what would you have done differently?
- How does the Aotearoa New Zealand situation resemble something you are familiar with?
- What could you recommend that could help us prepare to deal with the *Corbicula* incursion?

Desired outcome: An understanding of international experiences with *Corbicula*, and what would be the best course of action, based on historic examples from other invaded countries, for us to take.

3.2.3 TAG #2 – Tools and treatments

Key Questions;

- Which tools have been proven to work for what?
  - Costs and benefits of these tools.
- Which tools or treatments need field testing?
- Which tools should we try and employ now, in which environments?
- How to work within the Waikato catchment?
- Should surveillance include a "search and destroy" effort?
- How geographically wide should surveillance go?
- What may be trigger or decision points to move from eradication/elimination to containment?

Desired outcome: A plan for which tools, or combination thereof, to apply to specific areas in the Waikato River where *Corbicula* has been detected, for control and future surveillance.

3.2.4 TAG #3 - Infrastructure Impacts and Solutions

Key Questions;

- What are types of infrastructure that are most likely to be impacted? Do we have analogous systems in Aotearoa New Zealand?
- What are the biggest impacts?

  - How can these be mitigated?
- Within systems – what are the risk areas to target for treatments?
- Treatment options?
  - Are there any easy fixes?
  - Short term versus Long term fixes?

Desired outcome: Identification of the most practical, effective treatments and controls for different types of infrastructure.

3.2.5 TAG #4 – Check, Clean, Dry and behaviour change

Key Questions;

- What was effective or not effective in social behaviour campaigns overseas?
- How do we find balance between enforcement and voluntary actions?
- How can we prevent people from suffering "cleaning fatigue"?
- Have we identified all the different users and target audiences?
- Where and how to get the key messages across in the best, most effective way?
- What are the most practical and easy to use, but effective treatments to recommend to the public?

Desired outcome: Identification of the core messages and management of the social behaviour change programme to get the most value out of it.

3.2.6 TAG #5 - Translocations

Key Questions;

- Understanding risks and benefits of translocations for:
  - Elvers
  - Taonga species, using kākahi as an example
- In terms of:
  - Biosecurity risks of transfers happening versus not happening (baseline scenario)
  - Implications on population genetics
  - Protection of the species to ensure long-term survival

Desired outcome: Understanding how to support the continuation of culturally significant practices (such as the transfer of elvers) whilst mitigating the risks of spreading *Corbicula*. Collate ideas and expert thoughts on the critical factors from biological, ecological, and cultural perspectives on the translocation of native species that may be threatened by *Corbicula*.

4 International experience

4.1 *Corbicula* life history and the environment

It was noted by scientists who have worked both in Aotearoa New Zealand and other countries where *Corbicula* has invaded, that freshwater macroinvertebrate diversity here is lower. This may result in increased ecological impacts here than overseas due to less competition with and predation of *Corbicula.*

To be able to understand likely spread patterns of *Corbicula*, understanding the substrate preferences locally is important. *Corbicula* prefers sand and gravelly substrates, but dense populations have also been recorded on hard substrates, including concrete and man-made structures especially in high oxygen environments and fast flowing water (Lucy *et al*., 2012; Kelley *et al.,* 2022; Robb-Chavez *et al.,* 2023).

The Waikato River is a very altered and anthropogenically modified river system and is far from uniform and consists of a series of reservoir lakes with river sections connecting them. All possible substrates (*e.g.* mud, silt, degraded habitats all the way through to gravel and rocks) can be found in varying parts of the rivers (Gibbs *et al.,* 2023). Silt can be up to 40cm deep in places.

Floodplains with complex wetlands also exist in the lower Waikato. Wetlands could be an area where it is difficult to detect, eradicate or manage *Corbicula*. If they are found there, it would be important to prevent large populations building up in these wetland areas. Habitat mapping and hydrodynamic modelling of the Waikato will be important to help identify sites to survey and understand invasion patterns, especially for juveniles.

In invaded areas (where asexual reproduction is more commonly observed) there is no strict delineation between juvenile and adult *Corbicula* (Gomes *et al.,* 2016)*. Corbicula* juveniles are effectively fully formed individuals that are 0.25 mm across and connected to a mucilaginous byssal thread that enhances their ability to drift in fast moving or turbulent water, as well as allowing them to adhere to substrate or material that can aid its spread (*e.g.,* aquatic vegetation; Minchin & Boelens, 2018).

The Waikato River includes geothermal habitats. In Ireland and the Netherlands and other countries correlations were seen between higher temperatures and increased *Corbicula* abundance (*e.g.* thermal discharges from power stations with warmer temperatures have increased *Corbicula* density compared to the surrounding areas; Minchin, 2014; Morgan *et al.,* 2004; Bespalaya, 2021). This is likely due to increased temperatures accelerating growth rates and increasing food availability. Temperatures range from 9-25°C in the Waikato River (NZ EPA Report), and it does not freeze in winter, which is important to note as freezing has assisted some eradication attempts overseas in lake environments (Ruggles *et al.,* 2023).

Low temperatures will not prevent the establishment of juveniles or adults but may affect long-term reproductive success (Sousa *et al.,* 2008). It is likely seasonal temperature fluctuations relate to the number of reproductive events *Corbicula* undergoes annually in the Waikato River, as *Corbicula* requires water temperatures above 15 °C for reproduction (Modesto *et al.,* 2023). *Corbicula* is very tolerant of gradual temperature changes, between almost freezing and up to 36 °C, which is why sudden thermal shock is required to negatively impact them (Coughlan *et al.,* 2018; Coughlan *et al.,* 2019a; Coughlan *et al.,* 2019b; Coughlan *et al.,* 2021). Under favourable conditions, *Corbicula* can begin reproducing while still quite small (6-10 mm) and relatively young (3-6 months post-release from the parent) (Modesto *et al.,* 2023).

Lake depths also vary (up to 34 m in lake Karāpiro). Limited reports suggest that *Corbicula* can survive at depths greater than 100 m, however its favourable environment is more likely in shallower areas (Paschoal *et al.,* 2013). It points to a further need to delimit the depths to which *Corbicula* can be found in the Waikato River.

Natural vectors of spread do exist, especially for transference upstream such as waterfowl or gut passage through fish (Coughlan *et al.,* 2017). Newly emerged juveniles can readily adhere to potential vectors, substrate, or sediment with a single mucus byssal thread (Modesto *et al.,* 2023). Adults will only manage to temporarily adhere to surfaces if they manage to grip with their closed shell (e.g., clams will grip fishing nets), but this form of adherence only lasts while the clam maintains remains closed on the item caught between its shell. It should be noted that such "natural" spread is a minor contributor to *Corbicula* spread compared to human-mediated spread (Coughlan *et al.,* 2017).

There is no experience in Ireland of the effect of macrophyte beds in supporting *Corbicula* populations or enabling its spread. There are large, deep macrophyte beds in Lake Karāpiro, but it is uncertain what this might mean for the *Corbicula* population in the lake. If *Corbicula* can cling to aquatic plants this provides a pathway for spread. If aquatic plan fragments (with juvenile *Corbicula* stuck to it) attach to boats (*e.g.* ropes, anchors, propellers, etc) and isn't cleaned off, it may facilitate transport to other water systems. Juveniles are more likely to float than adults, especially in the weeks following their release after being brooded within the parent (Sousa *et al.,* 2008).

Small adults (7-14 mm) can use water pumping and mucus float lines to float downstream (Prezant & Charlemwat 1984). This behaviour can occur in response to water currents. In some locations they have been shown to move seasonally prior to the reproductive season (Williams & McMahon 1989). *Corbicula* are more likely to drag themselves along the substrate (Labaut *et al.,* 2021). River currents would be a greater factor impeding upstream dispersal, especially moving against anything stronger than low flows. It is thought that any natural upstream spread will be quite slow (possibly up to 1 meter per year by self-propulsion) and most upstream spread will be via anthropogenic activity (Voeltz *et al.,* 1998; Pereira *et al.,* 2017). Although boats and human-mediated movement are the most well-known anthropogenic pathways, sand and gravel extraction for industrial purposes and its movement can also be a big spread risk, as are irrigation tankers (Britton *et al.,* 2023). *Corbicula* adults can survive more than 30 days out of water if kept damp (Guareschi & Wood, 2020).

Corbicula may promote mass kākahi die-offs (through multiple avenues including competition for resources, higher filtering capacity and competition for substrate), possibly setting up a positive feed-back loop that results in making conditions more conducive to further *Corbicula* spread (Mouthon & Daufresne 2010; Labaut *et al.,* 2021). *Corbicula* have a rapid growth and reproduction rates, and quickly recolonise disturbed areas. In contrast kākahi, like native freshwater mussels (unionids) overseas have slow growth and reproduction. Thus, if *Corbicula* invades their biological niche and slowly reduces the kākahi biomass, it may further impact the ability of kākahi to survive any potential interventions taken to reduce *Corbicula* populations, as well as natural habitat variability and climate change.

4.2 Introduction pathways

In Ireland, the initial introduction of *Corbicula* was thought to have been deliberate for use as a food resource with subsequent spread likely being natural or accidental (via boats, fishermen (gear or live bait) or other human activity) (Caffrey *et al.,* 2016). Other invasive species, such as the zebra mussel (*Dreissena polymorpha*), have arrived in Ireland and Northern Ireland (either on the outside or via ballast water). For the incursion in Aotearoa New Zealand we as yet do not know the pathway of entry, however possible avenues are via internal ballast water in boats or the online trade of aquarium animals.

4.3 Actions taken

In the Irish experience, relatively little action was taken in "wild" open water systems (Sheehan *et al.,* 2014). The extent of the incursion was delimited for each river system affected following initial detection, and some local level movement restrictions were put in place. However, the impression was that as there was no mechanism of enforcing any restriction, they were largely ineffective. Of note, for one river that was resurveyed years later failed to detect *Corbicula*. The (unproven) hypothesis was that local flooding caused blackwater events and the subsequent anoxic conditions severely impacted the *Corbicula* population within the river.

Based on international experience, many of the group expressed that eradicating *Corbicula* from the Waikato River would be almost impossible based on the effectiveness of available eradication techniques. Containing *Corbicula* effectively within the Waikato catchment (in the areas where it is already established), to keep eradication (even in the long term) on the table was considered very important. It is also important to be clear in understanding the difference is between containment, local elimination and eradication. The consensus was that the elimination of any *Corbicula* populations detected outside the current known infested areas if they are detected early and not well established may be possible. This will require continuous surveillance across space and time to ensure any new *Corbicula* population is detected as early as possible to ensure the best chance of eliminating it.
Due to the non-specific nature of the control tools available, any actions taken will have impacts to the ecosystem and other non-target species that will need to be considered (Modesto *et al.,* 2023).

The necessity of rapid decision-making and action was considered imperative when dealing with this invader by the group. New decisions and new actions may be necessary as the situation evolves. The example used was the experience from *Didymo,* where without effective action it spread rapidly throughout the South Island. *Corbicula* has the potential to spread more widely given its biology, and much of Aotearoa New Zealand is considered suitable habitat based on climatic modelling (Torres *et al.,* 2018).

4.3.1 Cost Benefit Analysis (CBA)

In terms of decisions to be made on appropriate actions to take, it is important to take a long term, whole system view applied to the wider economy, environment and culture (an example was used of a €1 to €52 cost-benefit ratio from the InvaCost Global database) of the cost-benefit for eradicating invasive species when compared to the counterfactual or status quo scenario (doing nothing) (Haubrock *et al.,* 2021; Cuthbert *et al.,* 2022). The services of Ross Cuthbert at Queens University Belfast (r.cuthbert@qub.ac.uk), to set the scene for a CBA Invasion curve were recommended as a high cost of acting now may in the long term be a more economic option.

Potential CBA of any tools and/or interventions requires thinking about both a wider system view and a site-specific view (such as site-specific elimination, complete eradication from Aotearoa New Zealand or ongoing site-specific or wider control and population suppression). There is a need to consider timelines far beyond the immediate needs, impacts or costs. For example, what would the wider cost be to Aotearoa New Zealand in the long-term if no action is taken? Could it dwarf the costs of eradication attempts now? Any CBA must additionally include impacts on native species and impacts on traditional culture and way of life.

4.3.2 Research Gaps

The importance of identifying and addressing research gaps was highlighted, which would include the development of new tools and techniques for control and surveillance. This will aid early detection of new *Corbicula* populations, provide more options for management (suppression or local elimination) of any newly discovered populations, provide options to control the population more effectively in the Waikato River, and be of benefit to managing any other similar freshwater non-indigenous species in the future. Additionally, a better understanding of juvenile life stages was highlighted as a research gap, particularly what kills them effectively, and what is their survivorship time outside water.

5 Tools and treatments

5.1 Population control

Although recognised that eradication of *Corbicula* is unlikely in the Waikato River, there was a strongly expressed desire to act now - this would at least suppress the population. Any reduction in the *Corbicula* population will result in lowered propagule pressure (the number of juveniles in the waterway capable of spreading within the Waikato or further afield), thus reducing population spread and growth, as well as decreasing impacts on native biota and infrastructure (Sousa *et al.,* 2008; Ricciardi *et al.,* 2010).

Tools that currently exist to control or kill *Corbicula* are dependent on the habitat (depth, substrate, lotic/lentic, waterflow, etc), as well as the life stage of the organism. Chemicals (including molluscicides) are not as effective as physical removal given that *Corbicula* can close its valves and seal itself off, effectively avoiding exposure to externally applied chemicals (Coughlan *et al.,* 2019a). Additionally, when deployed in the environment, chemicals are rapidly diluted and result in off-target effects in the environment. Juveniles are more sensitive to chemical treatment, however the discussion clearly identified thermal treatments as the most effective way to kill *Corbicula* in the laboratory or in an isolated situation (infrastructure, boats, water sports or fishing gear). In an environmental or 'wilder' situation, benthic barriers were discussed as the most effective tool to suppress *Corbicula* populations, with the caveat that they also kill anything else under the barrier (Allen *et al.,* 2017).

The international TAG members had completed significant lab-based research on tools to kill *Corbicula*, but none were thought to be clear options for eradication on the scale that would need to be deployed in the Waikato River, but some could be useful for population suppression (Rosa *et al.,* 2015; Coughlan *et al.,* 2019a; Coughlan *et al.,* 2019b). It was suggested that in the local context, it would be worth field testing some of these tools and treatments (for example dry ice). There is an inherent difficulty in treating *Corbicula* in a 'wild' situation, as there is the ability for small juveniles to disperse during treatment or preparation for treatment, resulting in persistence of the population or spread downstream (Wittmann *et al.,* 2012). It was also noted that whilst a variety of tools had been tested separately, it would be worth understanding in the field how these may be applied synergistically (for example, adding dry ice below benthic barriers to increase initial kill and speed up anoxia). It was suggested that heavily infested and easily accessible parts of the Waikato River could be used to test treatments and combinations thereof.

The discussion of specific tools that could be useful for controlling or killing *Corbicula* populations covered the following points;

1. When *Corbicula* are fully exposed, then they can be killed with the direct application of thermal shock treatments such as with dry ice or direct exposure to flame (i.e., cold and hot temperature treatments, respectively). This is effective in killing but can be labour intensive and may be very difficult to scale up. The efficacy of dry ice and open flame is impacted by layering of other shellfish and certain substrates. It requires direct contact and may miss *Corbicula* buried in the substrate (which can be up to 15 cm). The substrate can be rotavated or ploughed to bring *Corbicula* to the surface, but there may be some risk associated with potential further spread by excessive disturbance (Coughlan *et al.,* 2018).

2. Hot water is a practical, simple version of temperature shock treatment to kill *Corbicula*. A minimum of a 5-minute immersion in >45 ºC water is needed to kill *Corbicula*. At >60 ºC the time comes down to a 1-minute immersion (Coughlan *et al.,* 2019a; Coughlan *et al.,* 2019b).

3. Benthic barriers were considered an effective tool to use. These can also be used in deeper waters and in faster flowing water if they either have valves are sufficiently weighted down and strong enough to cope with the build-up of anoxic gases that will occur as organisms die in the oxygen depleted environment beneath them. Benthic barriers will need to be made of a heavy rubber matting, so they are strong enough not to rip and are also impermeable. Gas permeable vs impermeable barriers were discussed, but to maximise efficacy impermeable barriers should be used. There was acknowledgement that there will be impacts on non-target species, but that the possibility of surveying the area and moving some native species (*e.g.* kākahi) from the area proposed to be covered is an option (Wittmann *et al.,* 2012; Allen *et al.,* 2017). Initial clam mortality rates are high (circa. 98-100%) within 1-2 months, but benthic barriers must be maintained for 3 months to increase the probability of achieving 100% mortality (Wittman et al 2012). At Lake Tahoe clam densities were 98% reduced after barrier removal and a year later remained >90% lower than in the control treatment, as did most other invertebrate species, aside from chironomid (midge) larvae which had increased (Wittman et al 2012).

4. Suction or mechanical dredging can be effective in shallow or deeper water and has had mixed success where used overseas. This is due to discontinuation (Ireland), and the ability of *Corbicula* to rapidly re-establish after suction dredging has occurred (USA). To provide sustained control (particularly where high concentrations are present), dredging needs to be repeated at any given site or combined with other control methods to maintain population suppression, but is an effective method to quickly reduce populations by 95% (Sheehan *et al.,* 2014). A plan to biosecurely dispose of all the *Corbicula* and material removed from the river is also required (Wittmann *et al.,* 2012; Sheehan *et al.,* 2014). Dredging could be useful in the Waikato context (e.g., at Lake Karāpiro) to markedly reduce populations thus reducing colonisation rates downstream and reducing the risk of transfer out of the Waikato. Lake Karāpiro is one of the most popular water sports venues in New Zealand and hosts national and international events. Follow-up with further dredging and control methods would be essential.

5. High-pressure water has been used on fish passages and weirs in canals in Europe, as well as on screens and intakes of plants to clear *Corbicula*. In some examples, this was used in conjunction with steam to kill *Corbicula* (high-pressure water will remove, but not kill *Corbicula*).

6. In some cases, chemical control and water blasting in enclosed localised industrial environments have been effective to remove *Corbicula.* Again, water-blasted *Corbicula* are not dead and their biosecure discharge and/or disposal must be planned for (Sheehan *et al.,* 2014).

7. High pressure steam is effective for localised treatments, especially in contained places such as power plants and other infrastructure. It is often used on an annual basis to decontaminate closed settings (*e.g*. industrial pipes) (Coughlan *et al.,* 2020; Coughlan *et al.,* 2021).

For points 5, 6 and 7 these are methods that will need repeating as *Corbicula* populations are likely to build up again over time as they re-colonise these environments if steps to retrofit infrastructure with fine screens or sand filters at water intakes are not taken.

8. Reducing the pH might be effective, but as with any chemical treatment the difficulty is effectively exposing *Corbicula* as, like most bivalves, they can close their shells for extended periods. The lowest observed pH tolerated within a wild population is 5.6 (Karatayev *et al.,* 2005). Low pH treatments are also likely to be highly detrimental to other macroinvertebrates/fish and may only have utility in closed systems.

9. Under certain circumstances hand picking of *Corbicula* might be of benefit.

10. The use of concentrated brine solution was considered. Currently there is no data on how effective it may be against *Corbicula*, or an understanding of how it may be deployed in the field (Roden, 2018; Coldsnow & Relyea, 2018). Laboratory trials would be necessary to establish brine toxicity. If used in conjunction with benthic barriers it might help to increase efficacy of the barriers in killing *Corbicula*, but again it would be a non-specific tool that may impact many native freshwater species. Salt treatments where *Corbicula* were exposed to salinities twice that of seawater resulted in limited mortality (Barbour *et al.,* 2013).

5.2 Decontamination

To decontaminate water sports or similar equipment, steam is considered the best method to ensure the organism is killed, with application of heat through immersion in hot water a close second. There is some data on Virkon being reasonably effective at killing juveniles, but any recommendation would emphasise hot water treatment for efficacy and practicality (Coughlan *et al.,* 2020).
Currently Check, Clean, Dry is promoted at boat ramps on the Waikato River due to several highly invasive species being present. However, there are no means available for the public to properly clean their watercraft on site as there are no washdown facilities at Lake Karāpiro boat ramps.

5.3 Surveillance tools

In the overseas experience, eDNA was not a tool that was used in surveillance. There was agreement that significant validation work in assay development, validation and refining sampling protocols would be required for it to be a useful tool for Response decision-making (Cowart *et al.,* 2018; De Brauwer *et al.,* 2023). Some discussion ensued about whether eDNA could be useful for tracking the original point of incursion of *Corbicula* spatially – this is likely very difficult. eDNA will likely be important in surveillance going forward, however, and the use of historic water samples could help detect *Corbicula* DNA without the need to physically return to sites. Additional molecular work using *Corbicula* DNA from the invaded population to build phylogenies could aid in tracing the origin of the Waikato incursion which may aid in identifying the pathway of entry. However, the genetic taxonomy of the *Corbicula* genus lacks clarity, so it may not be easy to do this work and is not regarded as an urgent priority (Sousa *et al.,* 2008).

The use of surveillance tools other than visual surveillance of wadeable areas or eDNA was discussed.

1. Dive and snorkelling surveys could be a useful way to search in areas that are deeper than wading allows, and to additionally understand the depth profile of *Corbicula* in the Waikato.

2. Colonisation surveys could be done by using a small, contained sand or gravel trap or something similar that can be placed in fixed locations and pulled out periodically to be examined for the presence of *Corbicula*. Some experimentation will be needed to determine what the best substrate is, but being a cheap and easy method of surveillance, these colonisation samplers can be deployed in quite a variety of environments and act as sentinels for early detection. They also work well where access to the river is difficult, or water conditions make visual or eDNA surveillance impossible. They are also suitable for citizen science groups and local stakeholders.

3. Grab or dredge sampling was suggested. A type of open frame net with a metal opening, or a small equivalent of a benthic sled could be used to throw from the side of the river and be dragged back to shore after which the trapped sediment could be sieved and examined for presence of *Corbicula*. What type of sampling frame is used at a given location will be determined by the substrate in that area that the frame will be dragged across.

When designing a long-term surveillance plan, a range of different methods will be required to increase confidence of detection. For example, man-made structures and geothermal areas might be surveyed in a different way or at a different frequency than some other sites due to them being suitable habitat for *Corbicula*. For waterways outside of the Waikato, prioritising sites (*e.g.* boat ramps at popular recreational lakes) connected by human activity to Lake Karāpiro or infested parts of the Waikato will be important (Schmidlin *et al.,* 2012).

5.4 Impact of killing *Corbicula*

Where *Corbicula* populations are dense, significant *Corbicula* mortality events (and large amounts of decaying shellfish) will add protein, carbon and nutrients and cause short periods of over-nutrification and eutrophication in areas where these mortalities occur which may lead to other negative impacts. Thus, thought needs to be given to extracting and disposing of dead *Corbicula* biomass, rather than leaving it in-situ (McDowell & Sousa, 2019). One possible impact of over-nutrification following a *Corbicula* mortality event is increased risk of avian botulism in wetlands, although scientific literature doesn't document high densities of *Corbicula* in wetland environments. In large lakes and areas with high flows (*e.g.* Lake Karāpiro), low oxygen and nutrient pulses will be less of a concern due to rapid dilution (*e.g.* when benthic mats are lifted).

Long-term releases of carbon, nitrogen and phosphorus into the ecosystem may also occur when there is a mass mortality of *Corbicula* from shell break down. Also, the presence of large amounts of shells provides hard surfaces for settlement and colonisation by a wide range of other organisms which can have both positive and negative effects. The 'shell surface' effect would have occurred prior to *Corbicula* death but will also create long term changes to substrates long after each clam is dead. Such rapid environmental changes following mass mortality events have been shown to facilitate other invaders in overseas contexts (McDowell & Sousa, 2019). If necessary, for example in shallow lakes, removal of *Corbicula* to covered landfill or offal pits on farms are methods to biosecurely dispose of dead biomass and associated material in the event of mass mortality events resulting from natural die-offs or due to a treatment being deployed. If not dead upon extraction, the *Corbicula* needs to be killed after removal. Tanks of hot water were identified as the easiest method for this purpose. Burial and or composting could also be effective, and shells may be used for fertilizer if biosecurity concerns were addressed.

5.5 Legal tools

Under the Biosecurity Act, if *Corbicula* was designated an Unwanted Organism (UO) or a pest in a regional pest management plan, this would provide some legal tools for managing risk movements. River iwi also could put a Rāhui in place to stop activity in an area. It was noted that enforcement of these tools was of equal importance to make them effective, especially based on the experience of the international experts.

6 Infrastructure impacts and mitigations

6.1 Understanding the infrastructure impacts of *Corbicula*

There are a large number of water takes from the Waikato River and given the impacts *Corbicula* has had on water take infrastructure overseas, there is a need to understand possible impacts in the Waikato (Isom, 1986).

Some specific concerns mentioned were:

- The motility, particularly of juvenile *Corbicula* in the water column may result in its entry into cooling systems of the Mercury Energy hydro plant (or other infrastructure), possibly resulting in the blockage of small end plates, as well as any diffusers and grates. Currently the cooling system is on a 4-year maintenance cycle and there was concern that this might need to be changed.
- Having a pump system into a 6 km long pipe, which is the case with one of the facilities, could be a point of vulnerability.
- The screens on pressure reducing valves are likely to be blocked, especially in plants using membrane filtration, where solids and particles will not get through.
- Concern about any wastewater and how and if it should be treated, especially as a potential vector of *Corbicula*.
- The 3 Waters sector is already under-resourced, and there are concerns that additional maintenance will mean significant impacts.

The water intakes at the Mercury Energy plant are 3 m below the surface, and 7 m above the lake bottom, which may already limit intake of *Corbicula*. International experts noted that the impacts seen thus far (in the Waikato River) seemed minimal. They made the point that if *Corbicula* has been here for quite some time already (>2 years), it is possible that the impacts don't significantly increase, especially if mitigation measures are pre-emptively implemented at individual industrial water takes now. The group noted preparatory work was extremely important. It is expected that *Corbicula* will accumulate in infrastructure, wherever sediment accumulates.

Of note, when developing Standard Operating Procedures (SOPs) and maintenance regimes, is that in other invaded areas *Corbicula* impacts on infrastructure have been very context dependent (Modesto *et al.,* 2023). In some cases, water takes from heavily infested areas have not resulted in significant uptake of *Corbicula* into infrastructure, and vice versa. Context-specific solutions will likely be required using knowledge of the specific infrastructure and the local environment. In areas where impacts were felt, the initial burdens were much higher than subsequently, when SOPs were developed and implemented.

When using treatments that kill *Corbicula in-situ*, the flesh degrades easily and rots, impacting water quality, and resulting chemical changes can cause corrosion to internals metals and pipework. Accelerated metal corrosion will result in shorter asset lifespans. The breakdown of *Corbicula* shells into smaller particles can penetrate further within infrastructure systems, and shell fragments are sharp and abrasive which can cause damage. Therefore, when developing mitigation protocols, the dead *Corbicula* should be both killed and removed from the system. Preventing entry in the first instance is more effective.

Many water treatment plants do not currently have process to remove taste and odour compounds, they are set up to remove organic and particulate material, and thus there may be additional impacts from decaying *Corbicula* in water treatment plants.

Corbicula density in the Waikato River has been reported to be in the hundreds of individuals per square metre, and highly infested sites overseas are 10,000-20,000 per square metre (Pereira *et al.,* 2016). This indicates the potential for significantly higher *Corbicula* impacts than those observed thus far.

Application of the framework on ecological economics of *Corbicula* (Sousa, 2008) to estimate costs to infrastructure operators may help gauge economic impacts on infrastructure in the Waikato.

Understanding the life cycle of *Corbicula* can help predict how, when, and in what volumes *Corbicula* can enter the infrastructure and determine subsequent management actions. The life cycle may be dependent on seasonality, local water conditions and other context-dependent factors unique to the given infrastructure (Sousa *et al.,* 2008).

Mapping the seasonality and temperature-dependence of the *Corbicula* life cycle onto Aotearoa New Zealand's seasons estimates that reproduction peaks will be Nov-Dec and Feb-Mar (Figure 1). This, however, requires validation through research in Aotearoa New Zealand. Of note, any warm water plumes (industrial discharge, geothermal etc) may stimulate 'out of season' reproduction. Also, temperatures in the Waikato River are relatively mild, thus almost continuous release of juveniles may occur, particularly through summer.

Season	WINTER			SPRING			SUMMER			AUTUMN			Source
Month	J	J	A	S	O	N	D	J	F	M	A	M	
Adults		>7mm disperse	>7mm disperse				>7mm disperse	>7mm disperse					1
Adults						Release juveniles	Release juveniles		Release juveniles	Release juveniles			2
Adults				When >15°C biomass maintained but R & shell G increase.		Biomass decreases as release juveniles			Biomass decreases as release juveniles				1
Lake Karāpiro water temperature		15°C					20-22°C	23°C					3

Fig 1. A proposed life cycle calendar of *Corbicula* in New Zealand (S. Clearwater, TAG communications, based on William & McMahon (1989) and Sousa *et al.,* (2008)). Adult clams >7 mm shell length will actively disperse downstream, secreting a mucus thread to float in water currents (Prezant & Charlemwat, 1984). G= Growth; R = Reproduction.

6.2 Mitigation measures

There is not a single fix or mitigation to prevent *Corbicula* causing major impacts in infrastructure – they must be both killed and removed from the system. Once in a system, reproduction and growth can lead to an increase in biomass, so decontamination processes must include removal of visible adults as well as possibly difficult to detect juveniles, which unlike adults may adhere to surfaces of internal infrastructure using their byssal thread.

6.2.1 Prevention

Of primary importance is to stop *Corbicula* entering systems via water intakes.

1. Screening at the intake
    a. New plants in areas where *Corbicula* is prevalent often have moveable baskets on intakes that filter *Corbicula* and are removed and cleaned periodically. Note retrofitting to existing infrastructure can be more difficult and expensive.
    b. Sand filters can be added at water intakes to block *Corbicula* from entering – note this will affect intake flows.
        i. Most water treatment plants use sand filters already located above flood level and require screens, pumps and treatment processes pre-filters. These will all be impacted by *Corbicula*.
    c. Hydrocyclones were suggested, with an example of the Waipā water treatment plant, as an option. These are used to exclude sediment and pumice, but no information exists on their efficacy in excluding *Corbicula* from water intakes (Nielson *et al.,* 2012).

2. Smaller, newer plants that use membrane filtration or take water from below the riverbed have different risk and impact profiles, as these would stop *Corbicula* entry. However, the high-pressure pumps that are required before membrane filtration are subject to *Corbicula* impacts.

3. Trying to minimise areas where sediment is trapped or settles within infrastructure – as *Corbicula* adults preferentially burrow a little bit in sediment or sit upon it rather than adhere to surfaces (Robb-Chavez *et al.,* 2022). They will settle where sediment settles.

4. Juveniles do stick to surfaces, but surface type is irrelevant as they adhere to anything their mucous strands can attach to.

5. Physical removal is required of larger *Corbicula*, especially as those already in the system as they may reproduce. High pressure water could be used to flush the system (noting killing and disposal of flushed *Corbicula* will still be required).

6.2.2 In situ treatments to kill *Corbicula*

In all cases where *Corbicula* is killed *in situ* removal of biomass is still required.

Physical methods

1. Steam causes mortality in 30 seconds, but it could be difficult to maintain temperature over the entire internal surface of pipework (Coughlan *et al.,* 2020).

2. Hot water is a good option for killing *Corbicula* (>45 °C for at least 5-10 minutes) but needs to be tested to ensure temperatures can be maintained across time and space in an industrial setting. Note possible difficulties in retrofitting heating elements to existing infrastructure, and the necessity of water discharge back into the Waikato River being below 35 °C.

3. Hot air was considered as a treatment option. Heat treatments (hot water and steam) as above are generally very effective. Hot air has not been trialled with reference to *Corbicula*, and likely a long exposure to a continuous jet of hot air would be required to ensure mortality, and a range of temperatures would need to be trialled. Required temperatures delivered are likely to need to be greater that 500 °C, for example a Bosch Heat Gun PHG 500–2 killed zebra mussels within 10 seconds (Coughlan *et al.,* 2020).

4. Water blasting plus chlorine treatments have been used to kill other molluscs. There is a dependency of chlorine treatments on water pH and temperature as well as immersion time, so these need to be considered, as well as managing any discharges.

5. In reticulation pipes, **saline ice** has been used in scheduled cleaning (for scouring). Would **saline and/or dry ice** work to kill *Corbicula*?
    a. There was no reported experience with saline ice, but dry ice would likely not flow through piping, and it is more likely that the solid ice pellets would clog and bind together.
    b. Dry ice is the solid form of CO_2 at -75 °C, it will bypass the liquid stage to gas as it sublimes. Dry ice is effective in killing *Corbicula* but is not useful in piped infrastructure (Coughlan *et al.,* 2018).

Note – points 1-5 are likely impractical for drinking water treatment plants.

6. UV light
    a. There is currently no real data on how long exposure would need to be to be effective.
    b. Unlikely to be effective against adults, as the UV doesn't penetrate deeply and therefore wouldn't kill *Corbicula* as the shell blocks UV irradiation of the tissue.
    c. UV systems are likely very effective at killing incoming juveniles when placed directly behind intake pumps – this requires testing.

Chemical methods

Chemical methods are not the preferred options for killing *Corbicula* as, like other bivalves, they can close their shells and protect themselves from the chemical for extended periods of time. However, in a closed environment, it is worth trialling a variety of chemical options in different contexts, especially in conjunction with physical methods (Lucy *et al.,* 2012; Meehan *et al.,* 2013).

1. Chlorine/hypochlorite is cheap and effective in a closed system if used at the right concentration for the right exposure time (Meehan *et al.,* 2013; Rosa *et al.,* 2015).
    a. 0.3 ppm could be used throughout the breeding season. If you are treating at end of the breeding season and can hold water in enclosed areas with a concentration of 1 to 2ppm for a week or two this may be effective. Testing of chlorination chemical by-products is also required before deployment, as Waikato River water has some unique organic compounds.

   b. Shock chlorination would entail 8-40 ppm for 4-6 hours – would require dichlorination before return to the environment.
   c. Weekly chlorination treatment of 1 ppm for 30 min has anecdotally been shown to be effective unless there is silt deposition that interferes with the chemistry.
   d. 2 ppm was used in Ireland, but the efficacy is context dependant (the individual plants and local water quality etc).

2. Biobullets
   a. Unsuccessful in open water systems but could be successful in closed systems such as pipes. They have been available for 10-15 years but have shown to have mixed results in terms of efficacy (Tang & Aldridge, 2019).
   b. There may be regulatory issues with the use of biobullets.
   c. Not enough evidence to suggest they will be practical or effective in the Waikato River.

7 Social Behaviour

7.1 Campaigns overseas

The Zebra Mussel incursion which was the first big biosecurity campaign in Ireland (late 1990s, early 2000s) was discussed as an example from which to learn. This campaign was resourced by multiple agencies and primarily consisted of lots of posters and a large amount of publicity. Local radio was used to get messaging out, as well as nature programmes on both radio and TV. Radio was found to be very effective. Ireland had Check, Clean, Dry messaging, but it was not used consistently, and sometimes it was known as Check, Clean, Disinfect, Dry. A lot of UK messaging was adapted and used in Ireland.

Some resources for messaging can be found here:
Check-Clean-Dry - National Biodiversity Data Centre (biodiversityireland.ie) and
EASIN - European Alien Species Information Network (europa.eu)

In Ireland there was inadvertent spread of *Corbicula* despite public messaging. Some of the key issues they faced were that it was hard to sustain messaging and due to historic and cultural reasons, people like to do their own thing and don't enjoy being told what to do. As such, there were negative feelings about being asked to change behaviour, so people still moved boats on trailers to other lakes/locations, and without readily available facilities to clean them. This made it unlikely that people would take appropriate actions. Besides boats, one of the biggest risks was felt-soled boots and waders (note – banned in Aotearoa New Zealand).

There was no regulation around managing *Corbicula* and it was thought that even if the regulation did exist it would be difficult to enforce. Maintaining impetus is one of the biggest challenges – people suffer "cleaning fatigue", or good intentions wane after a while despite messaging. In terms of targeting campaigns, it can be complex to predict where invasive species will spread, so difficult to identify areas to concentrate the messaging effort.

In Ireland they had lost the historic community stewardship of lakes, but in the past decade have formed river trusts. Ireland has a new national steering group for managing Invasive Species. *Corbicula* was not as big news as Zebra Mussel was, and there were no posters.

7.2 Campaigning in Aotearoa

Sustaining programmes is dependent on enthusiastic champions of the programmes, who come from within and are respected by their communities. A big strength in Aotearoa New Zealand is iwi that are intrinsically connected to place and are guardians of their sections of the river. Therefore, iwi kaitiaki/guardians or champions are well-placed to spread this message, and to define the appropriate manner of messaging to their iwi, hapu and whānau. Iwi would like to have their own ambassadors to target and educate the groups they interact with. As such, they can determine an effective engagement strategy on their awa – and their own strategy for Communications and Engagement around *Corbicula* biosecurity. Some additional notes when considering messaging for iwi:

- A key user group in the Maniapoto rohe are tamariki swimming.
- Maniapoto have a kura Taiao (environment learning group) – a small group of rangitahi (youth) who share information, including on *Corbicula*.
- It was recommended that messaging about the whakapapa (origins) of *Corbicula* is important when communicating how to manage them, incorporating Mātauranga where possible.
- Whilst having a desire to keep eradication on the table, there is also a need to learn and understand how best to live with what is currently in the Taiao.
- River iwi are working collaboratively on other kaupapa, so they have the networks in place with iwi environmental managers.
- One messaging approach could be sharing the video of *Corbicula* infestation at hui. This would be a very clear deterrent for public and regular users of the awa and other areas, giving the message that this is what our river or Te Arawa Lakes will look like if no one cares enough to take precautions.
- The tradition of river iwi, their culture and day-to-day connection to the awa will greatly help the biosecurity work.

There is also the example of Bay of Plenty (BoP) Regional Council and Te Arawa Lakes Trust (who are Check, Clean, Dry partners) where a compliance and enforcement approach is being trialled.

- See boat check sheet (Boat ramp self-certification (boprc.govt.nz))

The BoP Regional Pest Management Plan 2020–2030 requires that all boat ramp users Check, Clean, Dry - and then certify that their boat is free from freshwater pests, fish, and weeds (BoP Report, 2023). The boat then may be checked by biosecurity ambassadors that are active around the boat ramps. Additional use of “scare tactics” such as big signs in the water (two-sided so they are visible as one is heading out or coming back in) was discussed. It was noted that messaging will likely be slightly different (specifically for *Corbicula*) if you are entering or leaving a waterway, and whether that waterway is known to be infested or not.

7.2.1 Target audiences and messaging

Various stakeholder groups were engaged in Europe to spread the message to specific user groups: aquatic plant trade, ornamental fish, hikers/trampers, local anglers, boaters etc. In a similar manner to the iwi ambassadors described above, identifying ambassadors or champions within different stakeholders' groups and tailoring messages and messaging will increase awareness and stakeholder buy in. For example, messages, stakeholder groups and ambassadors may be different for Lake Karāpiro compared to the Te Arawa Lakes.

Risk groups and key river users in the Waikato that may be accidentally (or deliberately) transferring *Corbicula* to other areas of Aotearoa New Zealand were identified as including;

- Wakeboat users (ballast water in wakeboats are a high-risk pathway).
  - Including Wakeboarders.
- Jet skiers
- Other boaters, kayakers, rowers, canoers etc.
- Food cultivators who may deliberately move *Corbicula* to nearby waterways to increase its availability as a food source.
- Anglers, fishers using fyke nets etc.
  - *Corbicula* used as bait is an additional risk pathway.
- Hunting groups or trampers - crossing waterways in remote areas.
- Government agencies and University groups doing research or surveys.
- Casual aquarium collectors or people just picking up interesting shells.

Aquarium owners like *Corbicula* for the pretty colours and aquarium trade was identified as a risk pathway. It was noted that this risk is not addressed via Check, Clean, Dry messaging, and messaging that has been used in the past by the Department of Conservation (DOC) is appropriate: “Pests not pets”.

Check, Clean, Dry communications should be tailored to specific communities. Using this cleaning, washing and draining/drying methodology is a good approach, as even if it does not always kill *Corbicula*, it will significantly reduce passive vectoring (Barbour *et al.,* 2013). Ideally one should also prioritise high-use and high-risk areas such as boat ramps to deploy messaging and cleaning stations.

Currently the hydro lakes and river are open to the public and given this is unlikely to change, there is a lot of opportunity and need for signage and increasing public awareness. This includes the private and semi-private dam areas that are used for water sport. It would not be possible to limit access without legal enforcement.

It is also important to consider communication with industry bodies. If *Corbicula* starts to impact infrastructure in the Waikato River, or spreads to other regions, providing information to Water Utilities Managers will be important to mitigate infrastructure impacts. This could be done via groups such as the 3 Waters Suppliers, Civil Contractors Federation, and the Water Services Mangers Meeting (https://www.waternz.org.nz/events).

There is the need for clear, consistent messaging to provide to the public. It is also important to keep other invasive species in mind, so that the same programme can be used in the event of similar incursions to *Corbicula*. The best way to begin messaging for waterside biosecurity is to promote the use of the basics – Check, Clean, Dry. The incorporation of a disinfection step, whilst not totally effective for *Corbicula*, may be considered as it may work effectively for other invaders, and getting these processes ingrained in users is important, preparing the public for other biosecurity threats where disinfection may be critical.

Note resources from Ireland

[Invasive Alien Species (IAS) - Atlantic Technological University Sligo (itsligo.ie)]
[EASIN - European Alien Species Information Network (europa.eu)]

Developing messaging

To target different river users, co-creation should be the basis to develop communications tools and materials that specific ambassadors can share with their people. This co-development needs to be done in a safe space without judgement. Whilst some work may be required to get different groups around the table to discuss and work collaboratively, it is a better way to sustain change. The messaging needs to be targeted because one can put up thousands of signs and not get the message through. Different forms of communication appropriate for each group, and saturation of the messaging space are needed.

Building partnerships with boating/fishing/water sports clubs to ensure they can champion biosecurity – maybe including cleaning stations as part of their infrastructure – was proposed. This could also include club requirements to Check, Clean Dry.

As many river/lake users often don't realise they are creating a risk, material targeted for specific risk groups including specific examples of risky actions/behaviours typical of their group, simple ways to mitigate that risk, and the outcomes of not practising good biosecurity would likely be effective.

Types of messaging

Encourage positive 'peer pressure' amongst water users. Peer pressure can be very powerful if promoted as a culture of “good biosecurity behaviour” through positive reinforcement.

Kids are good ambassadors and can exert pressure on adults (their whānau especially). Outreach with kids is an important and powerful tool, especially bringing some aspects of *Corbicula* and freshwater biosecurity into the classroom. Within the Kura kaupapa Māori curriculum there are already elements of teaching about biosecurity. Targeting schools to build positive peer pressure via children to adults and the community may be a valuable avenue to pursue.

It is important to harness activities that increase ownership and a feeling of community in different waterbodies, whether known to be infested or not. Some examples are:

- For rowing, angling or other water-user clubs, offering biosecurity awards for their own internal biosecurity champions.
- At Lake Wairarapa there are Kākahi measuring days each year that are now run by Kahungungu iwi. This brings the community together around the lake.

It is equally important to discourage people from seeing the *Corbicula* as a useful resource in case it creates a perverse incentive to spread it. From early in the *Corbicula* response people were discouraged from eating *Corbicula* due to its ability accumulate toxins and bacteria. Food safety experts advise eating such an organism taken from a clean water environment only. “Invasivorism” (or control via harvest for food) has not been shown to be effective at controlling spread of invasive organisms.

Messaging needs to include following every step of the Check, Clean, Dry process to be effective. To help this, people do need to understand that the juvenile life stages may be invisible to the naked eye, as reminder to continue with Clean and Dry, even if the Check revealed nothing. In messaging, need to emphasise “just because you can’t see *Corbicula* on your gear, doesn’t mean they aren’t there”.

Wakeboats

Residual water left in ballast bladders or tanks on boats (particularly wakeboats) after they have been pumped is potentially a major vector for *Corbicula* with no clear approach to its management. There are no real treatments available, as hot water will be instantly cooled down and any chemicals would be diluted. Thus, existing Check, Clean, Dry messaging is unlikely to be effective for these types of boats with internal ballast tanks that are not readily accessible or drainable. A way to manage this risk may include regulations that restrict operation of a given boat to a specific zone or waterbody. Many boat users don't realise there are different river catchments within close proximity, so may not be aware that they are moving to a different catchment.

Wakeboat clubs could help manage this by making boats available for users that remain in specified waterbodies and are available to club members wanting to use different lakes or rivers. Wakeboating clubs already have boats at the clubs available for member’s use – increasing and publicising this may be one way of preventing boat movement and allowing people to enjoy their hobby. Clubs could additionally be engaged to promote and use their sites for cleaning and certification of cleaning of boats.

An import risk assessment is being done for wakeboats as it has been identified that if they have been used in water before being imported there will probably be residual water present. For example, some manufacturers pre-test a new boat by running it in water.

It will be important to reach out to wakeboat users and include them in any co-design process at the beginning, when developing messaging, regulations, tools, and treatments to manage this risk.

7.3 Enforcement

It was noted by Irish TAG participants that the efficacy of Check, Clean, Dry messaging requires more than education, it also requires enforcement. It is important to develop a real deterrent for deliberate spread. Ideally, one would stop all movement of boats and other anthropogenic movements from the infested system – this, however, may not have community buy in.

The example of an enforcement approach (self-certification of compliance) being undertaken at Te Arawa Lakes has already been noted.

There may be alternate ways to enforce movement controls without a specific legal tool. Using the *Didymo* example, on big stations in the South Island, there were requirements in the DOC permits issued for field work that vehicles would be sprayed down at each river crossing. Permitting requirements for certain activities can be modified to include conditions that limit spread of *Corbicula*. This may need co-operation with other government agencies.

7.4 Practical treatment for public to use as part of Check, Clean, Dry

Hot water is clearly the best, most effective treatment for the public to use at the Clean step, with immersion in hot water ≥45 °C for 5 minutes, or ≥60 °C for 1 minute and both are highly effective in inducing *Corbicula* mortality. The challenge is how to make it accessible for people to ensure ease of use. Providing any sort of infrastructure at boat ramps (or similar) for people to use could be expensive, create health and safety issues and would be subject to vandalism without constant oversight.

Although there is much discussion about chemical treatments, most of these have been shown to have limited or no ability to kill *Corbicula* which simply close their valves to avoid the chemical. Household washing powder and dishwashing detergent are not effective. Virkon has 93% efficacy for juveniles only but is not effective against adult *Corbicula* (Barbour *et al.,* 2013; Coughlan *et al.,* 2019), meaning it lacks utility as a generic control treatment. Messaging to the public needs to be generic and simple, so there needs to be a treatment that is effective against all life stages (and then will be the default treatment against a suite of other invaders).

If cleaning stations were developed, their location is of prime importance.

- Whether they are in infested places or uninfested places (stop *Corbicula* spreading out, or keep *Corbicula* from coming in).
- “Pop-up” cleaning stations at events could be effective in reaching large numbers of people in high-use areas.

There could be a requirement at certain waterbodies or events for people to come with “certificates of cleanliness”.

- They can use mechanisms such as a high-powered spray and the certificate is proof to show that they have cleaned the boat before arriving at an uninfested lake. Boats could be cleaned at cleaning stations on the route to a lake.
- There is a need to manage run-off from cleaning, both from cleaning stations and from individuals cleaning or draining their boat at home to ensure run-off doesn’t enter a stormwater drain and subsequently a local creek. This is where messaging regarding the juvenile ‘invisible’ life stage is important. Hosing (with tank or tap water) whilst exiting the water at an already infested site with run-off re-entering the already infested waterway is lesser of two evils compared to vectoring to a new site.
- An option to stop re-entry of run-off back into an infested waterway could be high-pressure washing with cold water on concrete or plastic sheets with run-off collected and channelled through a fine filter (*e.g.* sand) before returning to the waterway.

8 Translocations

8.1 How can the trap and transfer programme of elvers in the Waikato River continue safely?

8.1.1 History

Tuna (eels) are top predators in lakes and streams. There are three species in Aotearoa New Zealand, and they are of huge importance to iwi and hapu who are connected via whakapapa (a variety of relationships, depending on place). The history of eel fisheries is intertwined with the history of River Iwi and eels are considered a taonga, as they sustain their way of life and are highly nutritious. They were an everyday meal and very common, but after commercial harvesters began to extract them, there was a significant decrease in eel populations and availability. Human impacts such as pollution, development and climate change have also contributed to a reduction in eel abundance.

Mātauranga contains extensive information on ecology, biology and more relating to eels. The Waikato region is most celebrated in Aotearoa New Zealand for its quantity and quality of eels. All river iwi have fish and eel conservation management plans. The Karāpiro dam is a major blockage that impacts the migration of closely packed shoals of elvers moving upstream (Baker *et al.,* 2020). To complete their life cycle, elvers are transferred from below the dam to several hydro lakes above the dam, as well as some locations in the Waipā River.

The first elver transfer happened in 1987. From 1996-2022 the elver transfers were managed by commercial eel fishers and transfer data is recorded. Last year (2022) iwi took over the elver trap and transfer programme and it became more inclusive. Mana whenua involved schools and other community organisations and took the opportunity to educate the whole community on the importance of eels.

From a Māori perspective there are positive impacts for hapu that are the receivers of translocated eels - to be able to share food and welcome guests to their marae. These transfers have also brought the Waikato River iwi closer together via co-operating in this programme, and it is an important cultural practice that needs to continue.

8.2 How to mitigate risks associated with elver transfers?

Eels should not (and are not) transferred out of the catchment because of the risk of spreading disease. The ecological risks associated with translocations are greatly lowered when movements are confined to the same catchment (MacNeil, 2021).

There remains a possibility that *Corbicula* was transferred when moving eels, as the process involves taking eels and water from an infested zone to potentially uninfested zones. There is a need to continue this important cultural practice in a biosecure manner.

The elver transfer season normally starts around the beginning of December, continuing into February, but is dependent on the arrival of elvers at the base of the Karāpiro dam. It will be important to understand the life cycle of *Corbicula* in the Waikato, and whether at this time *Corbicula* juveniles may be floating in the water column and end up in the collection infrastructure for elver transfers.

To mitigate the risk of co-translocating *Corbicula* hitch-hikers, transfer water will need to be analysed, a key question for future research being "how many juveniles may be in the water at a given time, in a given volume of water?"

Treatment of transport and transfer tanks and the water therein will also be needed. This may be more difficult when there is a lot of sediment (which may harbour *Corbicula*).

8.2.1 Treatments

Treatments are required that won't harm elvers but kill juvenile *Corbicula*. Several options were discussed:

- Virkon aquatic is harmless to fish (and larger *Corbicula*) but kills juveniles in the water column and was used in a similar elver transfer program (Fisheries Ireland Report, 2021). Virkon Aquatic is currently not registered for use in Aotearoa New Zealand, only Virkon-S. There is a plan in place for registering Virkon Aquatic soon (possibly this year). It may be worth trialling Virkon-S on elvers and *Corbicula* juveniles.

- Formalin is another option to kill juvenile *Corbicula* but leave elvers unharmed. This is used in Victoria, and a protocol exists along with information on the toxicity of formalin to *Corbicula* (McKinnon, 2006; Layhee *et al.,* 2014)
- Iodine and vinegar/acetic acid were also identified as treatments worth investigating. Both would require some experimental work for use in this context (Cahill *et al.,* 2021).
- Saline treatment was an option noted that would likely kill *Corbicula* but not elvers, as elvers likely have a far higher salinity tolerance than *Corbicula*. Experimental validation would be needed (Crean *et al.,* 2006; Coldsnow & Relyea, 2018).
- To decontaminate water entering through the sluice gates at the Mercury Energy elver traps, it may be possible to fit UV treatment that would decontaminate water as it enters, this was thought likely to be effective against juvenile *Corbicula*.
- Within any trials, testing the synergistic effects of various treatments would be a good idea (*e.g.* the synergistic effects of multiple treatment mechanisms in series, such as UV then Virkon).
- Additional options may come from studying fish depuration processes (*e.g.* using ultrasound, gold nanoparticles, UV) and methods used at aquaculture facilities to disinfect surfaces for their efficacy in killing juvenile *Corbicula*.
- The Cawthron Institute have produced protocols over the last 10 years for moving cultured fish around the country and managing potential 'hitchhikers', as well as for decontamination of bivalves. These could be trialled for the elver transfer process (Tremblay *et al.,* 2017; Cahill *et al.,* 2021).
- When adult eels are moved, awareness is needed of the potential for co-translocations in the gut as *Corbicula* survives gut passage for up to 40 days in some fish (Coughlan *et al.,* 2017). There will be a need, if adult eels (or any other fish species) are moved from infested areas of the Waikato for a transition through biosecure quarantine to ensure gut contents are purged (depurated) before relocation.

8.3 The use of "arking" and translocations to protect populations and genetic diversity of kākahi and other native species

This concept was discussed with relation to possible impacts if *Corbicula* populations increase to levels where they severely impact native species. There may then be a requirement to translocate native species to preserve their unique genetics (Germano *et al.,* 2015). In the event this is required, plans should be prepared to mitigate biosecurity risks of *Corbicula* spread and ensure genetic diversity in both the translocated and destination populations are maintained, and that origin and destination sites are prepared in a culturally appropriate manner. Kākahi were discussed as an exemplar of this process, but many of the principles are relevant for other native species that may be impacted by *Corbicula* populations.

8.3.1 Background

Each waterway can be considered a distinct hapu of genetics for kākahi, as the geographic isolation of populations creates diversity. This is also seen in limpets and other bivalves. Kākahi translocations have been made successfully to Zealandia to preserve genetics and test translocation methods. An established protocol for freshwater translocations from the UK was adapted for use in this study (Killeen & Moorkens, 2016). However, this unique genetic diversity can be swamped when populations are translocated, as has been observed in fish populations in UK and Europe and is a natural effect of population mixing. The counterfactual is doing nothing and the possible loss of these kākahi populations in infested areas may be far worse than the loss of genetic diversity. The questions of where and when to translocate are regarded as decisions for iwi and hapu to make, guided by their interests.

There may be other reasons for translocating kākahi or other native species, for example to shift them temporarily out of the way of while benthic barriers or other *Corbicula* control tools are being trialled. This would also allow one to protect some of the kākahi within the same part of the lake or river when conducting any experimental trials for control work.

8.3.2 Risks and benefits and the "hows"

Translocating at-risk native species such as kākahi was noted by some as an action of last resort, if *Corbicula* came to dominate an ecosystem, as it is possible that a translocation will do more harm than good, therefore it is best to be risk averse (see MacNeil, 2021 for a risk assessment of freshwater translocations in Aotearoa New Zealand). It would be important to do a Risk Assessment on the site one is translocating to, to understand the risk of *Corbicula* establishing there.

Potential population control measures for *Corbicula,* as mentioned above, are largely non-specific. The possibility exists that native species can be removed in advance of deploying control measures, and then reintroduced when conditions become safe. There will be risks associated with reintroduction, although likely lower than an initial translocation (Germano *et al.,* 2015).

In the event translocation is decided as the correct course of action, decisions around site selection (both origin and destination) are needed. These decisions should be made by the Iwi and Hapu with tikanga over the sites, with appropriate assistance, if required, from biosecurity personnel. In iwi-led translocations, karakia (prayer) to the awa (river) creating space for the species in question to grow has been vital in ensuring successful translocation.

Releasing pheromone into the destination site has been used in the past to acclimate translocated native species, helping them adjust to the new site, as does Taki Ihirangaranga (sacred vibrations of sound), and understanding the whakapapa of the way for translocated species such as kākahi. It is also important to note the phases of lunar cycle, as there are certain times that are appropriate for translocations to occur.

Kākāpō provides examples of successfully managed translocation, including their recent reintroduction to the nearby Sanctuary Mountain Maungatautari, and the use of mātauranga to prepare and manage this. There was a process of asking, giving, and receiving to ensure compatible genetics. This was a long process requiring a lot of relationship building. The process can be accelerated in emergencies, but relationships are still important. Therefore, it is important to start this thought process now.

The vulnerability status of the kākahi (kāeo) from the DOC threat perspective provides information on whether a translocation for arking is appropriate (Grainger *et al.,* 2013; Grainger *et al.,* 2018).

- One kākahi species *Echyridella menziesii* (Gray, 1843) is 'At Risk, declining' and is found throughout Aotearoa New Zealand.
- *E. aucklandica* (Gray, 1843) 'Threatened, Nationally Vulnerable' (is distributed mainly Waikato northward, also with disjunct populations in Whanganui, Wairarapa and Hauroko (Sth Island)).
- There is one other (known) species of kākahi (*E. onekaka* (Fenwick & Marshall, 2006) 'Data Deficient') found in the northwest South Island.
- Different species of kākahi have different Conservation Statuses, as above, and 'Threatened' is a higher status of risk than 'At Risk'.
- Threat status of *E. onekaka* was 'Naturally Uncommon' in 2013 and was changed to 'Data Deficient' in 2018.

Anecdotally populations appear to be in decline in many places. For example, they appear to be declining in some shallow lakes (e.g., Lake Ohinewai (Waikato), Punahau, Lake Horowhenua (Fenwick and Clearwater 2018)), but stable and/or thriving in other lakes (e.g., Rotorua, some O Tu Whare Kai/Ashburton lakes (Burton *et al.,* 2022)). In streams both *E. menziesii* and *E. aucklandica* (in particular) may be declining and dying out due to habitat degradation and fish passage issues (native freshwater mussels require a fish host to complete their life cycle). *E. aucklandica* requires smelt *Retropinna retropinna* to complete its life cycle. Smelt are fish that are affected by barriers to fish passage (*e.g.,* culverts and weirs) as they are 'poor climbers' thus loss of these fish from inland waterways may be contributing to other habitat pressures that are causing freshwater mussels to decline (Grainger *et al.,* 2013; Grainger *et al.,* 2018). Generally, there is a lack of recruitment in freshwater mussel populations and in some cases, they are considered locally extinct. We have limited knowledge of kākahi populations in larger rivers, due to the technical and logistical difficulties of surveying them effectively.

Indications are that it might be time for a formal assessment of kākahi populations and their vulnerability status, however we need population survey data to update the Threat Status. A good example is Waikato Regional Council's recent report that documents 5 years of survey data and makes management recommendations including habitat and fish passage restoration (Melchior *et al*., 2023).

A wadeable river survey protocol is available (Catlin *et al*., 2017) and a nation-wide freshwater mussel conservation group has recently reconvened and plans to collaborate on survey protocol development (Catlin *et al.,* 2017).

Not all overseas experience with *Corbicula* suggests deleterious impacts. *Corbicula* may change the environment in ways that don't impact native species, however this is likely to be dependent on the density of the *Corbicula* population. The densities that *Corbicula* populations reach in the Waikato relative to those seen in other invaded areas will be critical to monitor to understand the impact on native species – but high densities would likely mean high impacts. In Ireland or in the UK no specific actions were undertaken to protect native species from *Corbicula* as there were no vulnerable species at the heavily infested sites.

It is hard to ascribe the loss of species to a single invasive when several invasive species often invade simultaneously. One study in France suggests there are impacts on native bivalve diversity and numbers, but sometimes, this may be due to a subsequent, more impactful invader (Mouthon *et al.,* 2010). Kākahi are likely to be outcompeted by *Corbicula* even though they are much larger, as *Corbicula* are very effective filter feeders, and have a high growth rate and a high reproductive rate (Geist *et al*., 2023). *Corbicula* can quickly recolonise an area after a disturbance (e.g., a flood, or a mass clam die-off) and will eventually outcompete slower growing native shellfish.

Population dynamics and age cohorts of both populations, especially in relation to each other, need to be understood. It is conceivable that at high densities *Corbicula* may use kākahi as a substrate. It was noted that Zebra or Quagga mussels are likely significantly worse threats to kākahi should they invade and establish because these species attach permanently to hard surfaces and grow (*Corbicula* do not attach permanently). Zebra and Quagga mussels both produce tough byssal threads (similar to the 'beard' of New Zealand's green-lipped mussels) and attach to a settlement surface. If they attach to a living mussel they foul the shell competing for space and food, inhibiting the native mussels ability to move, feed, reproduce and grow (i.e., causing shell deformities) and increasing mortality rates (Sousa et al. 2011).

Any detrimental effects on kākahi may be ecosystem/environment dependent, so the impact of *Corbicula* in the Waikato remains to be seen. Other invaded areas have seen improved water clarity as large populations of *Corbicula* effectively filter out phytoplankton. There is evidence they can change the plankton community itself and ultimately lake food webs, selectively feeding on some plankton species and rejecting others (Bolam *et al.,* 2019). How this affects native species is not known. It may increase aquatic plant growth which could be beneficial in some locations (e.g., in shallow turbid lakes), and detrimental in others where pest aquatic plants already form large problematic weed beds

<u>*Biosecurity challenges when Arking:*</u>

- The requirement to quarantine kākahi to ensure *Corbicula* aren't co-translocated:
  - A fortnight quarantine at 15ºC water temperature or higher to allow for depuration of gut contents is likely required, work is needed to evaluate how this works in relation to *Corbicula*, and if it is even necessary.
  - Supplementary feeding of kākahi while in quarantine is recommended, especially when large numbers of mussels are being held. This can be difficult to manage, but de-activated algae is a good option.
  - Kākahi also excrete large quantities of ammonia so it is critical to filter any recirculating water effectively (pre-primed biological filters - standard good practice aquaculture).
  - Kākahi have successfully been held in captivity for many months.
- In the past when translocating kākahi from Lake Wairarapa to Rotomahanga in Zealandia Te Māra a Tāne, ecosanctuary it was undertaken under a 26ZM3 DOC permit (McEwan, 2022).
- Translocation requires research to examine whether kākahi ingest juvenile *Corbicula*, as they eat algal filaments that are ~350 microns in length. Juvenile *Corbicula* are 250 microns in length and probably slightly smaller in shell 'height'. They may not be an attractive food item to kākahi which "taste" their food prior to ingesting, but if they end up coated in mucus and bacteria juvenile *Corbicula* could be incidentally eaten by kākahi.

- Important to understand the risk profile of the sites - both origin and destination, particularly with reference to future *Corbicula* invasion, as there is no point carrying out a translocation to a site that could itself be vulnerable to *Corbicula* invasion anytime in the future.
- Preferable to use sites where there is some modicum of control at the site and researchers can manage the environmental conditions.
- Frequent monitoring and adaptive management of sites is important, and the need to have a Plan B if things don't proceed as hoped with the translocated population (mark translocated individuals, monitor etc).
- Need to test the options for non-destructive sampling from kākahi to understand disease or parasite load, and how best to ensure translocated kākahi are free from all relevant diseases and parasites.
- All the logistics could be pre-tested and practiced so they are ready to go if required, for example if a translocation is needed to save a threatened population of a native species. Any processes developed will be useful for any future incursions.

External decontamination of Kākahi

Collecting and keeping kākahi in quarantine will allow trials of cleaning protocols for kākahi to prevent the movement of *Corbicula* juveniles that may be attached to their shells.

- Acetic acid has been used previously to disinfect kākahi.
- A suite of trials focussed on decontamination methods for small juveniles not visible to the naked eye would be very useful. They may prove to be easier to kill than those say, 3 mm length and larger (Davis *et al.,* 2015; Cahill *et al.,* 2021).
- Any toxicity trials that are conducted should aim for 100% kill within 5 minutes to support easy decontamination.
- Ideally test methods on zebra and quagga mussels and other high risk invasive bivalves to future proof the Check, Clean, Dry programme and develop a suite of effective tools. These species are not yet present in Aotearoa New Zealand
- Could use freshwater mussel husbandry protocols that are already available. The protocols are focussed on conservation of native species but could be modified for quarantining. Methods for external cleaning and handling needs to minimise stress to the mussels (Horton *et al.,* 2014; Patterson, 2018; Aldridge *et al.,* 2023).

9 Summary

9.1 *Corbicula* control

Corbicula has never been eradicated from an invaded location before, so eradicating from the Waikato River is extremely unlikely. The consensus was that suppression and containment in the Waikato River will minimise the likelihood of spread to the rest of Aotearoa New Zealand, as well as maintain a possibility of eradication at some stage in the future. As such, actions include;

- Continued surveillance to detect any newly established populations of *Corbicula* in places it is not currently known to be.
  - Alternate methods for surveillance could be trialled such as colonisation plates or hand dredges.
- Commence work on trials and research to develop and validate tools to kill *Corbicula* – this includes testing combinations of known tools to understand synergistic effects. Methods trialled in the Waikato can then be applied if *Corbicula* is detected outside the Waikato.
  - The best starting point would be benthic barriers – these could be trialled in conjunction with other treatment options such as
    - Temperature shock treatment (during drawdowns); or
    - Adding organic matter beneath rubber matting (*e.g.* Uwhi mats); or
    - Brine
- Contain *Corbicula* within the Waikato with strict and enforced movement controls (hold the line to contain in Waikato for now until more information and tools are developed).
  - Movement controls of people, equipment, sand/gravel extraction and water (tanker) transfers.
- Eradicate any newly discovered *Corbicula* populations outside the Waikato if the population structure, abundance and area of infestation suggests it is not well established.
- Work on suppression within the Waikato catchment with a long-term view based on a strategy of containment leading towards eradication as methods are developed.
  - Work to eliminate *Corbicula* in small sections - start upstream and work downstream.
  - Removing *Corbicula* reduces propagule pressure in the Waikato and nation-wide.
- It is worth doing a Cost Benefit Analysis (CBA) to assess the long-term control costs versus the costs of the impact of an uncontrolled *Corbicula* incursion which may help decide where to prioritise resources.
- If it is eventually found in multiple sites outside the Waikato, reassess long term management goals.

9.1.1 Tools/Infrastructure

The best tool to kill *Corbicula* is still hot water (≥ 45 ºC for 5 minutes), but other tools and treatments are worth testing, especially in contained infrastructure. In these cases, several steps are necessary – preventing *Corbicula* entry, killing *Corbicula* in the system and removal of dead *Corbicula*. This will likely need to be to be done on a regular basis if it is not possible to prevent entry of juveniles. Each facility needs to develop its own context-specific SOPs pre-emptively to prepare, including considerations for any retrofits to intakes or other infrastructure. Changes in maintenance programmes and scheduling can also be planned. Preventing *Corbicula* entering infrastructure is best (*e.g.* sand filters), but cleaning using flushing with hot or high-pressure water, or chlorination treatments are the most practical methods for control once they are in a system. Subsequent removal of dead *Corbicula* is then required. The environmental impacts of hot water and chlorination discharges must be managed. It is possible to use UV systems at intakes (dependent on volume and intake structures) to minimise entry of live juveniles.

9.2 Communications programme

Continue to use and develop the Check, Clean, Dry programme. There needs to be a strong emphasis on good messaging and communication, targeting both the public and industry. A clear need was identified for specific messaging co-developed with each stakeholder group.

- Messaging needs to be multifactorial, via many different media avenues and very hard to miss.
- Signage needs to be visible from all sides and needs to hammer home that **ALL** steps of the Check, Clean, Dry process need to be followed (not just stop after "Check") and that this needs to be part of the education.
- Make maximum use of all stakeholder groups (including Ambassador/Champions in iwi, community groups, sports groups etc) as well as education of children to provide "self-policing" and positive "peer pressure" to continue to spread the message over time.
  - Noting that positive reinforcement and building a critical mass of people enacting good biosecurity behaviour is better than a negative calling out of poor behaviour.
- Provide support and materials that are co-designed to help all iwi and community groups develop their own messaging programmes.
- The campaign will have to be revitalised from time to time to stop "cleaning fatigue".
- Make use of clubs to provide cleaning facilities and practical ways to help the public take the actions required to stop the spread.
- The best tool for killing *Corbicula* is hot water – can we provide facilities for this to happen?
- Consider "pre-cleaned" certification for boat movement or restricting boats to one waterway (especially wakeboats) to manage the risk of further spread within Aotearoa New Zealand.
- Wakeboats are a major risk that needs to be managed – need to focus management of that risk at the border, as well as internally (internal ballast tanks are very difficult to fully drain and decontaminate).
- Enforcement and regulation are important to manage the risk of spread – even ambassadors can help with "non-official" enforcement in a similar manner to that which Honorary Fisheries Officers work. Another good example is the self-certification that is deployed at Te Arawa Lakes.

9.3 Translocations

Several possibilities exist to continue translocating elvers safely, by treating elvers in a manner that kills *Corbicula* but doesn't harm the elver. It is worth considering trials to determine the best methods before the next elver transfers will occur. Options include;

- Virkon Aquatic (trials possible with Virkon S which is currently available).
- UV light.
- Saline solution.
- Acetic acid/vinegar.
- Iodine.
- Formalin.
- Treatments used in conjunction with each other.

It would help to understand when the juvenile *Corbicula* concentrations in water are highest.

Arking and translocating of kākahi (and/or other native species) should be considered on a case-by-case basis. Ensuring plans and protocols are ready are a useful investment in management of these native species.

- Decide appropriate destination locations based on environment, kākahi genetics, and Hapu knowledge at place.
- Ensure culturally appropriate preparation of both the origin and destination sites.
- Test destination location and populations to ensure its safe for the translocated species.

- Biosecurity precautions must be taken for translocation.
    - Quarantine facilities are available (*e.g.* University of Waikato and NIWA at Hamilton).
    - Potentially “wash” the outside of the kākahi to get rid of external pests.
    - Test for disease or manage the disease risk profile to ensure low risk.
- If possible, translocate kākahi or other species within the same catchment or river to protect the population while *Corbicula* suppression measures are trialled.

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Appendix 3. Check, Clean, Dry Processes for *Corbicula* and Aquatic Pest Plants

This document shows Check, Clean, Dry processes for *Corbicula* compared to the regular Check, Clean, Dry processes for didymo and aquatic pest plants. These are taken from the BNZ website in October 2024 and may be changed over time. There are also additional processes for different activities and gear items.

Check, Clean Dry for *Corbicula*

CHECK CLEAN DRY

When you move from the controlled stretch of the Waikato River (which is from Whakamaru Dam to the river mouth at Port Waikato) to another part of the river or its lakes, you must follow the Check Clean Dry procedures for the exotic freshwater clam for all watercraft, gear, or clothing that has come into contact with river water.

Some North Island regions are also requiring water users in their area to follow these Check Clean Dry procedures. Check with your local regional council for their specific requirements.

Note, Check Clean Dry procedures to prevent human spread of the exotic freshwater clam will also manage other freshwater pest species.

Check

- Remove any visible matter, including any clams you can see, along with plant material or mud. Drain all river or lake water.

Clean

- Wash down your gear, vehicle, watercraft, and trailer that has been in contact with river or lake water with tap water onto grass, beside the waterway or at home and not into a stormwater drain system. This will remove any remaining invisible material.
- For absorbent surfaces and materials that have been in contact with river or lake water (including carpet on trailers) use an appropriate treatment in the treatment options table on this page
- Treat residual water that always occurs when on-board ballast bladders or tanks have been pumped.

Dry

- Allow gear to dry to touch, inside and out, then leave it to dry for at least 48 hours (2 days) before using again.
- Dry areas inside the watercraft where water has pooled, for example with an old towel, and then leave the craft to dry for at least 48 hours (2 days). The hull of a watercraft will dry when towed.

Treatment options for gear made of absorbent material

Type of treatment	Method
Hot water	Above 60°C for at least 1 minute, or Between 50 to 54°C (hot household tap-water) for at least 5 minutes, or Above 45°C for at least 20 minutes.
Freezing	Until solid (that is, freeze overnight).

Other treatment options

Type of treatment	Method
Bleach	Mix household bleach in a 10% (1 in 10) ratio with water and immerse for 1 hour.
Isopropyl alcohol	70% isopropyl alcohol, taking care as it is toxic and flammable, and there are requirements around storage and transport of isopropyl alcohol.

Note, the Check Clean Dry advice may be adjusted as further technical information becomes available or the need arises. Refer to the manufacturer's instructions for gear and any commercial treatments.

Corbicula Check, Clean, Dry https://www.mpi.govt.nz/biosecurity/exotic-pests-and-diseases-in-new-zealand/active-biosecurity-responses-to-pests-and-diseases/exotic-freshwater-clams-corbicula/#how-to-prevent

Standard Check, Clean, Dry for Didymo and Aquatic Pest Plants

The 'Check, Clean, Dry' method

To prevent the spread of invasive freshwater pests (like didymo), whenever you move between waterways you must check, clean, and dry all your gear that comes into contact with water. If you don't want to treat your gear, make sure you only use it in one waterway.

Check

Remove any plant matter from your gear and leave it at the site (the river or lake bank), or put it in the rubbish. Don't wash plant material down any drain.

Clean

Use 10% dishwashing detergent mixed with water and leave the item wet for 10 minutes.

The rule of thumb for 10% detergent mix is:

- for a 250ml (small) spray bottle, put in 1 and half tablespoons
- for a 500ml (large) spray bottle, put in 3 tablespoons
- for a 10-litre bucket, put in 1 litre of detergent.

Dry

Ensure your gear is completely dry to touch, inside and out, then leave dry for at least another 48 hours before you use it (didymo can survive for months on moist gear).

Cleaning options

Option	Amount	Treatment time[2]
Dishwashing detergent or nappy cleaner	10% mix	Soak or spray all surfaces and leave wet for at least 10 minutes
Bleach	2% mix (200mls diluted to 10 litres in water)	Soak or spray all surfaces for at least 1 minute
Hot water[1]	Above 60°C Above 45°C	Soak for at least 1 minute Soak for at least 20 minutes
Freezing		Until solid

[1] 60°C – hotter than most tap water; 45°C – uncomfortable to touch

[2] Allow longer times for absorbent items.

In addition, there are different Check, Clean, Dry processes for different activities and items, such as kayaking; Jet boats, jet skis, and outboard motor boats; machinery, vehicles, people and animals

Standard Check, Clean, Dry https://www.mpi.govt.nz/outdoor-activities/boating-and-watersports-tips-to-prevent-spread-of-pests/check-clean-dry/

Freshwater gold clam *(Corbicula fluminea)*

Biosecurity New Zealand
Ministry for Primary Industries
Manatū Ahu Matua

The freshwater gold clam (also called the Asian gold clam or Asian clam) is a small shellfish that reproduces rapidly, forming large groups that can clog water pipes and out-compete native species. It was first found in May 2023 in the Waikato River at Bob's Landing near Lake Karāpiro.

About the clam

This shellfish is native to eastern Asia but has become widespread in North and South America and Europe where it has become a pest, breeding rapidly, forming large groups and clogging up electricity generation plants, irrigation systems and water treatment plants. They can potentially compete with native species for food.

Overseas, the freshwater gold clam has proved difficult to control and eradication has never been achieved.

Corbicula fluminea is an unwanted organism under the Biosecurity Act, which means you must not knowingly move them or water that might contain them.

Biosecurity New Zealand is partnering with mana whenua, the Waikato River Authority, the Waikato Regional Council, Te Papa Atawhai Department of Conservation and Toitū Te Whenua Land Information New Zealand to understand and respond to this incursion.

Help us find the clam

Look out for these unusual shellfish. The adult clams are 2–3cm in length and are typically dirty white, yellow or tan in colour.

Freshwater gold clam
Photo: Tracey Burton, Toitū Te Whenua Land Information New Zealand

They have an obvious ribbed texture on the shell. These clams are found in freshwater or brackish water (near river mouths), sitting on top of sandy or muddy surfaces, or buried shallowly within them.

You may see their shells partly exposed, or syphons (their breathing tube) sticking out from the sediment. They can also be found among debris, such as leaves, that may have settled on the riverbed.

Freshwater gold clams on the riverbed at Bob's Landing, Waikato River – Photo: Tracey Burton, Toitū Te Whenua Land Information New Zealand

If you find freshwater gold clam

- note the location
- take a photo if possible – of the clams and also the area around them
- contact Biosecurity New Zealand on 0800 80 99 66
- or complete the online reporting form at https://report.mpi.govt.nz/

Do not eat freshwater gold clam

These small shellfish filter-feed and eat deposits from the river or lake bed. Because of this, they can accumulate toxins in their gut.

October 2023

Freshwater gold clam (*Corbicula fluminea*)

Biosecurity New Zealand
Ministry for Primary Industries
Manatū Ahu Matua

Help stop spread – Check Clean Dry

Before moving:

If you move from parts of the Waikato River where *Corbicula fluminea* has been detected to another area where it has not, or any other freshwater environment such as another lake or river, or any brackish water such as an estuary, you must:

Check – for what is visible

Remove any visible matter, including any clams you can see, along with plant material or mud. Drain all river or lake water.

Clean – for what is not visible

Washdown your gear, vehicle, watercraft, and trailer that has been in contact with river or lake water with tap-water onto grass, beside the waterway or at home and not into a stormwater drain system.

For absorbent surfaces and materials that have been in contact with river or lake water (including carpet on trailers and lifejackets) use an appropriate treatment in the treatment options table (top right).

Treat residual water that always occurs when on-board ballast bladders or tanks have been pumped.

Dry – to be sure

Gear: Allow gear to dry to touch, inside and out, then leave it to dry for at least 48 hours (2 days) before using again.

Watercraft: Dry areas inside the watercraft where water has pooled, for example with an old towel, and then leave the craft to dry for at least 48 hours (2 days). The hull of a watercraft will dry when towed.

Note, these steps will also prevent the spread of other freshwater pest species.

For more information, including any updates, visit: www.biosecurity.govt.nz/clam

Treatment options for gear made of absorbent material

Hot water	Soak in hot tapwater (55°C) for at least 5 minutes
Diluted bleach	Soak in household bleach in a 10% (1 in 10) ratio with water for 1 hour.
Freezing	Until solid (that is, freeze overnight).

Note: Refer to manufacturers' instructions for any treatments on gear.

Similar-looking species

Small freshwater gold clams may look like native pea-clams or small freshwater mussels (kākahi/kāeo). The key features to look for when distinguishing freshwater gold clams are deep ribbing on the shell, the symmetrical shape and colour.

Smaller kākahi can have a similar golden colour and ridges but are more elongated and asymmetrical.

Native pea-clams are pale, very small (generally less than 6 mm), more circular and without the ribbing of gold clams.

Top: Adult kākahi.
Middle: smaller kākahi.
Bottom, left to right: juvenile kākahi; native pea-clam; j uvenile freshwater gold clam.