Location and productivity of īnanga (*Galaxias maculatus*) spawning grounds in the Arahura catchment

Shane Orchard

Prepared for

Department of Conservation
July 2020

Cover photograph:
View of the tidal waterways and floodplain islands in Arahura River lagoon. Photo: S. Orchard

Waterlink Ltd
CONSERVATION PLANNING • RESOURCE MANAGEMENT
439 Marine Parade, Christchurch 8062
Aotearoa / New Zealand
T: +64-3-388 8281 | M: +64-21-318548

Document revision and status

Revision	Date	Status	Approved by	Issued by
v1	15/07/2020	Draft for client review	S. Orchard	S. Orchard
vFinal	30/10/2020	Final	N. Kunzmann	S. Orchard

Location and productivity of īnanga (*Galaxias maculatus*) spawning grounds in the Arahura catchment

Shane Orchard

Prepared for

Department of Conservation
July 2020

Report WL20062 for Department of Conservation

TABLE OF CONTENTS

1. Introduction

1.1 Background

This report summarises results from field surveys of the Arahura River lagoon system to support the Arahura River Restoration Project on the South Island's West Coast. The focus of these surveys was to improve the understanding of locations used by īnanga (*Galaxias maculatus*) for spawning. Īnanga is a migratory fish that is the most abundant of the five galaxiid species that support New Zealand's whitebait fishery (McDowall 1984). At the Arahura River the fishery has important cultural values for Te Rūnanga o Ngāti Waewae and the Arahura Marae is located close to the river a short distance from the coast.

Investigations were undertaken to characterise the tidal range and locate spawning sites to provide a baseline for future monitoring and support restoration work. Prior to this project, there were no previously reported spawning sites in the river system despite there being an abundance of suitable habitat for adult fish. This is provided by an extensive lagoon complex of lowland waterways, small lakes and associated wetlands that extend both north and south from the Arahura River mouth (Fig. 1).

Īnanga is currently listed as an 'at risk - declining' species in the New Zealand Threat Classification System (Dunn et al. 2018), in recognition of historical decline. Many threats to īnanga are associated with waterway degradation and habitat loss associated with land-use intensification trends (Department of Conservation and Ministry for the Environment 2000). These effects have generally been more severe in lowland waterways where īnanga are found. Despite this, there are also opportunities to reduce human impacts. Some of the best opportunities involve fine-scale spatial planning to integrate conservation measures and production land. These approaches are assisted by identifying critical locations that may be limiting population sizes or producing bottlenecks at key life stages. For īnanga, these critical habitats include migration routes and spawning grounds that are essential for completion of the life cycle.

Īnanga has a highly specialised spawning behaviour that is synchronised with the lunar tides. Adult fish congregate near river mouths and lay their eggs in riparian vegetation on spring high tides (Benzie 1968). Unfortunately, the specific location of īnanga spawning habitat on the margins of lowland waterways often results in spatial overlap with human activities. During the spawning season, these may pose threats to successful spawning by reducing the availability of suitable habitat or impact on the survival rate of eggs after spawning has occurred (Hickford & Schiel 2011a; Orchard et al. 2018a). Common examples include riverbank engineering, drainage and other hydrological modifications, and disturbance activities such as vegetation clearance and grazing. Establishing the location of spawning sites provides essential information for assessing their co-occurrence with potential threats.

1.2 Scope

The scope of this project included:

a) a survey of salinity characteristics on a representative spring high tide;
b) surveys of īnanga habitat quality across the rivermouth system to support subsequent spawning site surveys following Orchard & Hickford (2018); and
c) spawning surveys in March and April 2020 with the objective of locating spawning sites.

The remainder of this report is set out as follows: Section 2 describes the field survey methodology, Section 3 presents findings from the field surveys, Section 4 discusses management opportunities, and Section 5 provides a summary of the main conclusions for future monitoring and potential restoration work.

Fig. 1. Overview of the Arahura River lagoon system showing major water features visible in recent aerial imagery. Extensive changes have occurred since December 2019 in the area indicated, illustrating the dynamic nature of the rivermouth system. See imagery comparisons in the results section below.

2. Methods

2.1 Salinity survey

The salinity survey was completed on 10-11 March 2020 with the objective of establishing the upstream limit of salt water intrusion and estimating peak salinity values at as many locations as possible across the lagoon system. The survey was timed to follow the incoming tide upstream following Orchard & Hickford (2018). At each monitoring site, measurements were taken at the bottom and 10 cm from the top of the water column. Salinity monitoring sites are shown in Fig. 3.

River flows were typical of a moderate fresh that was receding after a period of rain. Water levels were observed to be relatively high (in relation to local landmarks) due to the combination of the spring high tide and river flow. For example, water levels were knee to thigh depth on the 4WD track leading to floodplain islands from the access track at Old School Road.

The tidal heights and times were 1205 / 3.6 m (10 March) and 1252 / 3.7 m (11 March) according to the New Zealand Hydrographic Authority tide predictions for Charleston, with the 11 March tide being the largest predicted tide for the month.

2.2 Spawning site surveys

2.2.1 Egg searches

Spawning surveys were completed for the March and April spawning events (Table 1). The census survey approach was used with the objective of locating all spawning sites in the catchment (Orchard & Hickford 2018). To delineate the search area, results from the salinity survey and riparian vegetation inspections were used to assess habitat condition for spawning using set criteria to define areas of high, moderate and poor quality habitat (Table 2). Areas of moderate and high quality habitat were then searched systematically to detect egg occurrence. This involved conducting three searches at random locations for every 5 m length of river bank in these areas, using a team of three people. Each search inspected the stems and root mats of the plants along a transect line perpendicular to the high water mark. Typically, each transect covered a 0.5 m wide swathe of vegetation 1-2 m long depending on the bank slope and degree of difficulty locating the high water mark. Where eggs were found the survey was extended at least 50 m either side of the last occurrence to establish the dimensions of each site and look for others nearby.

2.2.2 Area of occupancy (AOO)

All egg occurrences were associated with a given location that was identified as a spawning site. GPS coordinates were recorded using hand-held units in the field and corrected in QGIS v3.4 (QGIS Development Team 2020) with the assistance of site photographs and landmarks. Individual sites were defined as continuous or semi-continuous patches of eggs with dimensions defined by the pattern of occupancy (Orchard & Hickford 2018). For all egg occurrences, the upstream and downstream extents of the patch were established, and the length along the riverbank measured. The width of the egg band was measured at the position of each search transect falling within the spawning site, and with a minimum of three measurements taken at all sites. Zero counts were recorded when they occurred within a spawning site, as is common where the egg distribution is not a continuous band. Area of occupancy (AOO) was calculated as length x mean width for each site.

2.2.3 Spawning site productivity

Productivity was assessed by direct eggs counts using a sub-sampling method (Orchard & Hickford 2016, 2018). At each transect, as above, a 10 x 10 cm quadrat was placed in the centre of the egg band and all eggs within the quadrat counted. Egg numbers in quadrats with high egg densities (>200 / quadrat), were estimated by further sub-sampling using five randomly located 2 x 2 cm quadrats and the average egg density of these sub-units used to calculate an egg density for the larger 10 x 10 cm quadrat. The mean egg density was calculated from all 10 x 10 cm quadrats sampled within the site, inclusive of zero counts. Productivity was calculated as mean egg density x AOO.

Table 1. Tidal cycle data and survey periods.

Survey Month	Peak tidal cycle start	Peak tidal cycle end	Peak tidal height* (m)	Spawning survey dates
March	Mar 10	Mar 12	3.7	Mar 16 - 18
April	Apr 8	Apr 10	3.7	Apr 28 - May 1

* predicted tide levels above Chart Datum at Charleston (Lat. 41° 54' S Long. 171° 26' E) (Source: LINZ).

Table 2. Habitat quality classes.

Class	Quality of habitat for supporting spawning	Expected egg mortality rate	Criteria
1	Poor	High	Vegetation cover <100% or Stem density <0.2cm^{-2}
2	Moderate	Moderate	Vegetation cover 100% Stem density >0.2cm^{-2} Aerial root mat depth <0.5cm
3	High	Low	Vegetation cover 100% Stem density >0.2cm^{-2} Aerial root mat depth >0.5cm

Classification schema

Vegetation cover <100% Class 1
Vegetation cover >100% Class 2 or 3
Stem density <0.2cm^{-2} Class 1
Stem density >0.2cm^{-2} Class 2 or 3
Aerial root mat depth <0.5cm Class 2
Aerial root mat depth >0.5cm Class 3

3. Results

3.1 Salt water intrusion

The salinity survey was completed on a relatively large tide (Table 1) combined with a moderate fresh in the river. The survey was conducted on two days to help address the large area involved, with the northern lagoon and waterways surveyed on 10 March and the southern tributaries the following day (Fig. 2).

The 10 March survey commenced at 10.30am and was timed to capture the spring high tide. Terrain covered included the mainstem true right bank below the State Highway 6 road bridge, lower floodplain islands, Flowery Creek and tributaries, and lagoon shoreline in this vicinity.

The 11 March survey covered the true left bank downstream of the road bridge and waterways in the vicinity of Greyhound Road. On both days, strong in-flowing tidal pushes were observed on the incoming tide.

Fig. 2. (a) Water levels on the peak of the tide on 10 March in the northern tidal creek above the Flowery Creek junction were sufficient to inundate pasture on the DOC land boundary. (b) view of the southern tributary near Greyhound Road.

North bank survey, 10 March

Initial measurements taken along the north bank of the main river prior to the predicted time of high tide showed an absence of salt water intrusion into the near-shore channels among the floodplain islands even in the presence of strong tidal pushes (Table 3). Soon after, surveys were conducted in the northern section of the lagoon commencing at the Flowery Creek confluence at 1200. The first detection of salt water was made at 1235 in the northern lagoon several hundred metres downstream of the Flowery Creek confluence (Fig. 3). At this time water levels were observed to have dropped by ca. 20 cm from the tidal peak. However, these observations suggest that the upstream limit of salt water was likely to have been confined to the lagoon basin and entrance of Flowery Creek on this particular tide.

South bank survey, 11 March

Strong tidal pushes into the southern tributaries near Greyhound Road were observed during the incoming tide, and included significant in-flow to the small lake in this vicinity. Bottom salinity in the lake (2.7 ppt) was initially higher than in the tributary channels, which are shallower, indicating that higher salinity waters had entered the lake on previous tides (Table 3). Salinity levels peaked around 1300 as expected, and by this time bottom salinity in the entrance channels was higher than measured in the lake (5.5 ppt), consistent with this being a relatively large spring tide. Pulses of up to 6.2 ppt were measured on tidal pushes in the lower reaches of these tributaries which are relatively close to the main stem of the Arahura River.

At the upper end of the small lake brackish water was found in small side creeks and drains which terminate in small wetland areas but have little discernible baseflow from the adjacent land. The upstream limit of salt water in the stream beside Greyhound Road was measured at a prominent stock race adjacent to the farm buildings on the seaward side of Greyhound Road (Fig. 3), although tidal inflow (of baked-up fresh water) was observed beyond this point.

Table 3. Salinity observations in the Arahura River on spring high tides of 10th and 11th March 2020.

Location	NZTM coordinates		Date	Time	Salinity (ppt)	
	X	Y			Top	Bottom
Arahura River mainstem near end of Old School Road	1438229	5274294	10-Mar-20	1050	0	0
in channel adjacent to 4wd track	1438353	5274520	10-Mar-20	1105	0	0
near tip of triangular island on floodplain	1438468	5274615	10-Mar-20	1115	0	0
at channel confluence near whitebaiting hut	1438495	5274638	10-Mar-20	1125	0	0
farm gate above Flowery Creek confluence	1439403	5275237	10-Mar-20	1140	0	0
200m above Flowery Creek confluence	1439354	5275207	10-Mar-20	1150	0	0
100 m above Flowery Creek confluence	1439265	5275158	10-Mar-20	1155	0	0
opp. Flowery Creek confluence	1439163	5275097	10-Mar-20	1200	0	0
300m downstream from Flowery Creek	1438944	5274983	10-Mar-20	1210	0	0
400m downstream from Flowery Creek	1438840	5274968	10-Mar-20	1220	0	0
junction of the tidal waterway channel with main lagoon	1438689	5274887	10-Mar-20	1230	0	0
in northern lagoon 50 m from farmland	1438595	5274920	10-Mar-20	1235	0	0.2
in northern lagoon opp. whitebaiting hut	1438420	5274884	10-Mar-20	1245	0	0.6
top end of small lake true left	1438089	5274125	11-Mar-20	1155	2.1	2.7
mid section of small lake true left	1438084	5274175	11-Mar-20	1200	2.1	2.4
ephemeral waterway near small lake	1438051	5274182	11-Mar-20	1205	2	2.1
lake entrance channel at blind end	1438023	5274254	11-Mar-20	1210	3	3.3
in lake entrance channel	1438020	5274269	11-Mar-20	1214	5.1	5.5
in lake tributary at the riffle section near willow	1437976	5274330	11-Mar-20	1218	3.3	4.5
at confluence of lake tributary & Greyhound Rd stream	1437947	5274374	11-Mar-20	1222	5.7	6.2
Greyhound Rd stream 50m above lake tributary	1437914	5274353	11-Mar-20	1228	5.5	6.1
Greyhound Rd stream, first riparian wetland entrance	1437890	5274310	11-Mar-20	1235	5.5	5.9
Greyhound Rd stream, second riparian wetland entrance	1437828	5274258	11-Mar-20	1240	5.2	5.6
Greyhound Rd stream at sharp bend near farm track	1437746	5273991	11-Mar-20	1250	0.5	1.5
Greyhound Rd stream on straight above sharp bend	1437628	5273931	11-Mar-20	1255	0.1	0.4
Greyhound Rd stream at culvert opposite farm sheds	1437414	5273819	11-Mar-20	1310	0.1	0.1

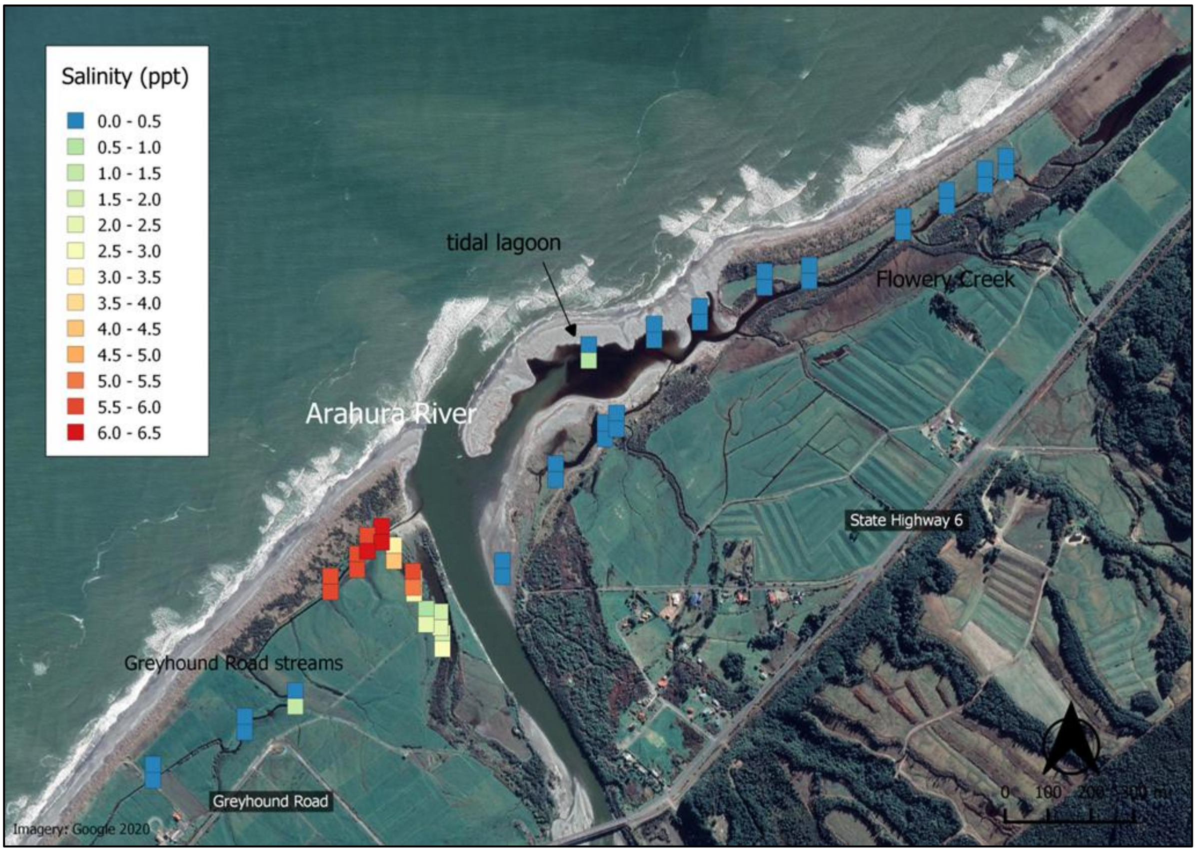

Fig. 3. Maximum salinity recorded on the spring high tides of 10-11 March 2020 at the Arahura River. At each monitoring point the bottom icon is bottom salinity, and the top icon is salinity measured 10 cm from the top of the water column.

3.2 Īnanga spawning activity

3.2.1Location of spawning sites

March survey

In the March survey, 12 sites were found in four distinct locations across the wider lagoon system. These four areas are shown in Fig. 4 and are referred to elsewhere in this report, as follows:

- The first location is in the northern tidal waterways where two spawning sites were found, one of which was a large site located opposite the prominent confluence in the lower section of Flowery Creek.

- The second location, where two sites were found, is a wetland area in DOC land near the confluence of two small un-named streams that drain nearby farmland.

- The third location is a series of channels and floodplain islands in the centre of the lagoon area, many of which experienced major changes in the December 2019 storm events. A total of four sites were found in this area, two of which were relatively large.

- The fourth location is the southern tributary streams near Greyhound Road where a total of four sites were found in March, and others in April. The largest of these was located in the outlet channel of the small lake (shown in Fig. 1), and the smaller sites were located along the main stream that runs roughly parallel to Greyhound Road.

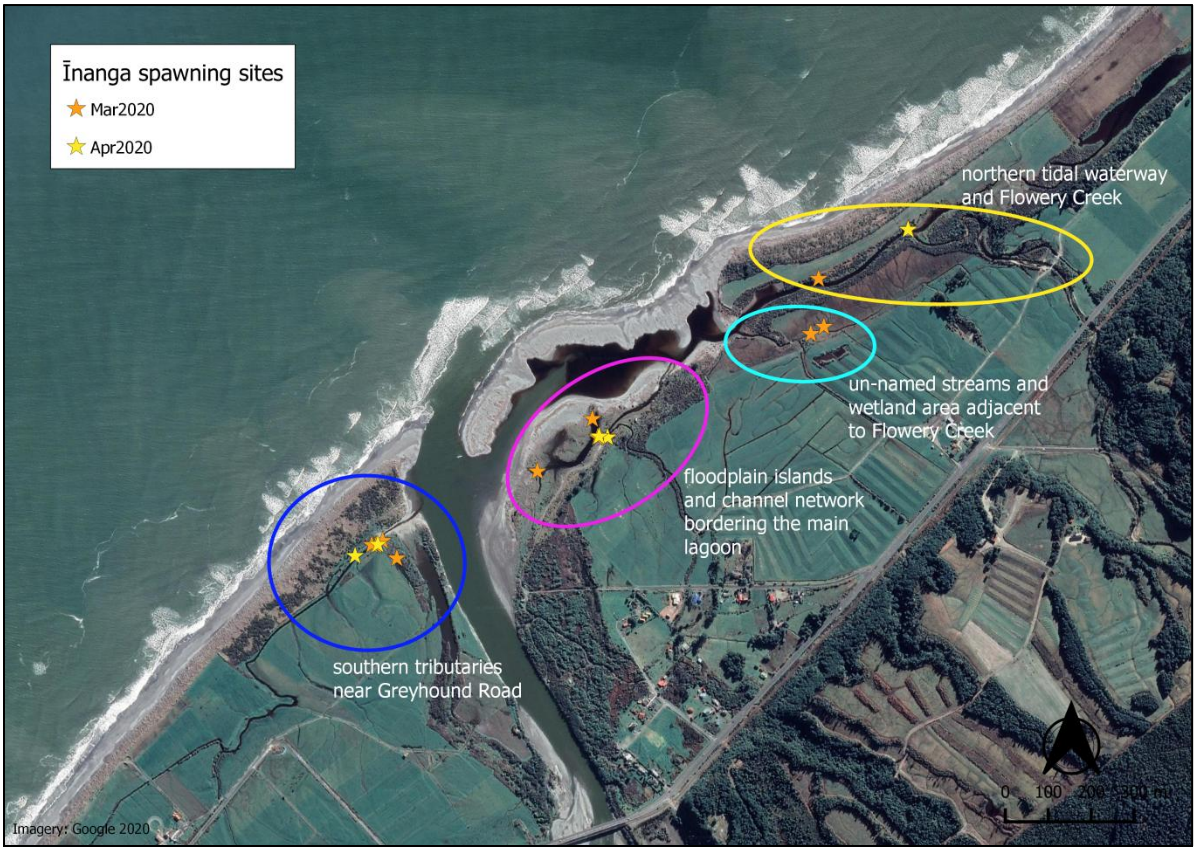

Fig. 4. Four locations where īnanga spawning sites were found in 2020 within the wider Arahura rivermouth system. All four areas feature smaller tributary waterways with complex hydrological connections to the main river and lagoons.

April survey

In the April survey, less spawning was found overall, and all sites were located in similar areas to those found in March. A total of five sites were found, one in the Flowery Creek area, two in the floodplain island area, and two in the southern tributaries near Greyhound Road as described above.

A series of floods occurred during the April that may have smothered some eggs, and the spawning sites were typically harder to find than in March due to these effects. The April spawning sites were also slightly higher in elevation (5 - 10 cm) than the March sites. This suggests that spawning event coincided with a fresh in the river consistent with the weather pattern at the time.

In the Greyhound Road streams, all of the sites used in March were found to have been smothered with silt by April, resulting in a reduction in the extent of good quality habitat overall. However, in the Flowery Creek and floodplain islands areas, the three April spawning sites were all located in the same vegetation patches as used in March, with only small differences in their position between months. Although some of these areas were also silt-laden, differences in the degree of silt loading were also noted within the vegetation, and this may have had a bearing on the selection and size of spawning sites.

3.2.2 Area of occupancy (AOO)

The total area of occupancy (AOO) of spawning sites was 46.0 m^2 in March and 17.5 m^2 in April (Fig. 5). Due to repeat use of three sites between months, there were a total of 15 individual sites recorded overall.

The largest individual site (18 m^2) was located opposite the Flowery Creek confluence as seen in Fig. 6a. Another relatively large site (3.1 m^2) was found in the wetland area adjacent to Flowery Creek in March (Fig. 6b). In the floodplain islands area, two relatively large sites (9.3 and 2.9 m^2) were found in March (Fig. 6c). Both were used again in April with AOOs of 6.1 and 6.7 m^2 respectively.
In the southern tributaries, only one relatively large site (5.5 m^2) was found in March (Fig. 6d). Other sites found in this area were relatively small in both months despite an abundance of good quality spawning habitat.

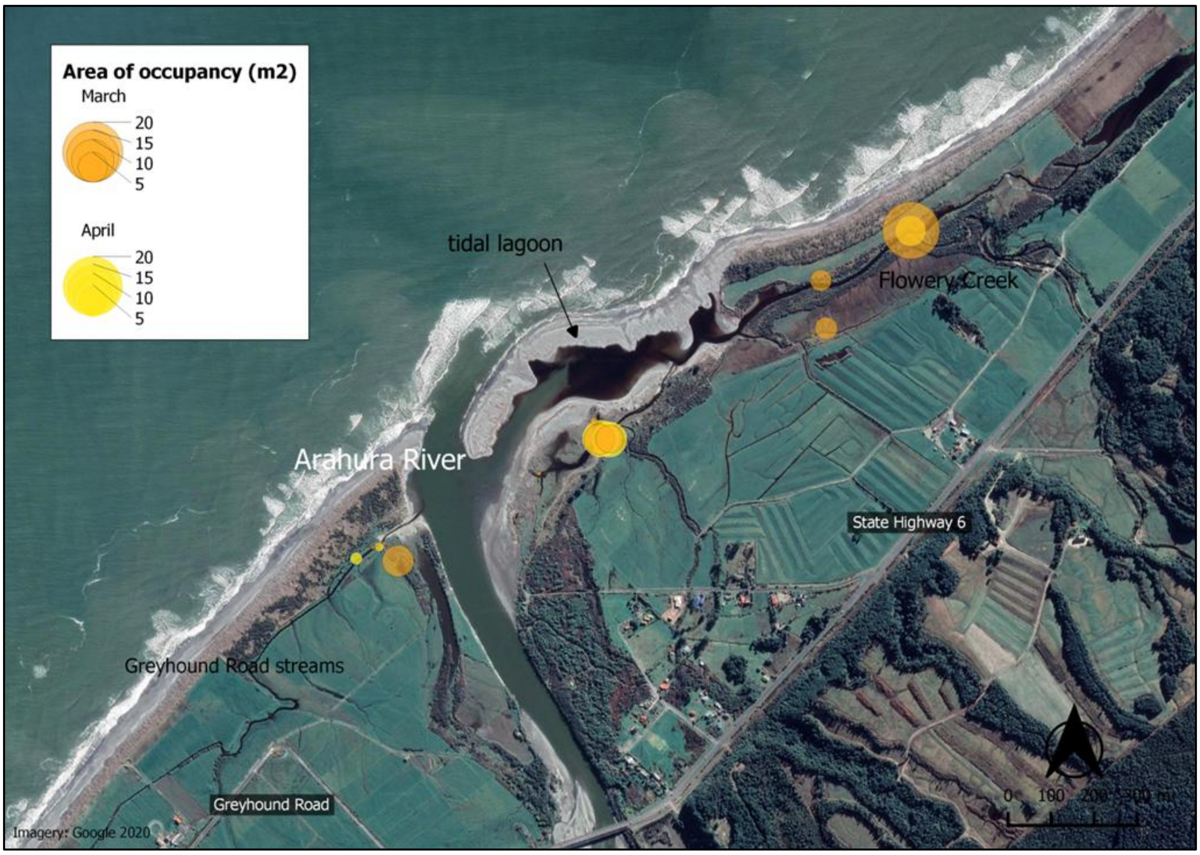

Fig. 5. Location and size of īnanga spawning sites in the Arahura catchment in March and April 2020.

Fig. 6. Examples of relatively large īnanga spawning sites in the Arahura catchment**.** (a) in the northern tidal waterway opposite the Flowery Creek confluence,(b) in the wetland area adjacent to Flowery Creek, (c) one of the sites in the floodplain islands area, (d) beside one of the southern tributary streams that connects with a small lake.

3.2.3 Egg production

In March, the total egg production was nearly 1.5 million eggs with the largest site (site 1, in Flowery Creek) contributing over 1 million eggs (Fig. 7). The highest egg density per site (5.9 eggs / cm^2) was also found at the Flowery Creek site. This site was located in clumps of tall fescue (*Schedonorus arundinaceus*) and was used again in April (see site photo, Fig. 6a).

Most of the remaining egg production was contributed by site 4, in the wetland area (shown in Fig. 6b), and site 9 in the southern tributaries (shown in Fig. 6d), with smaller contributions from other sites (Fig. 7). Across all sites the mean egg density was 1.8 eggs / cm^2.

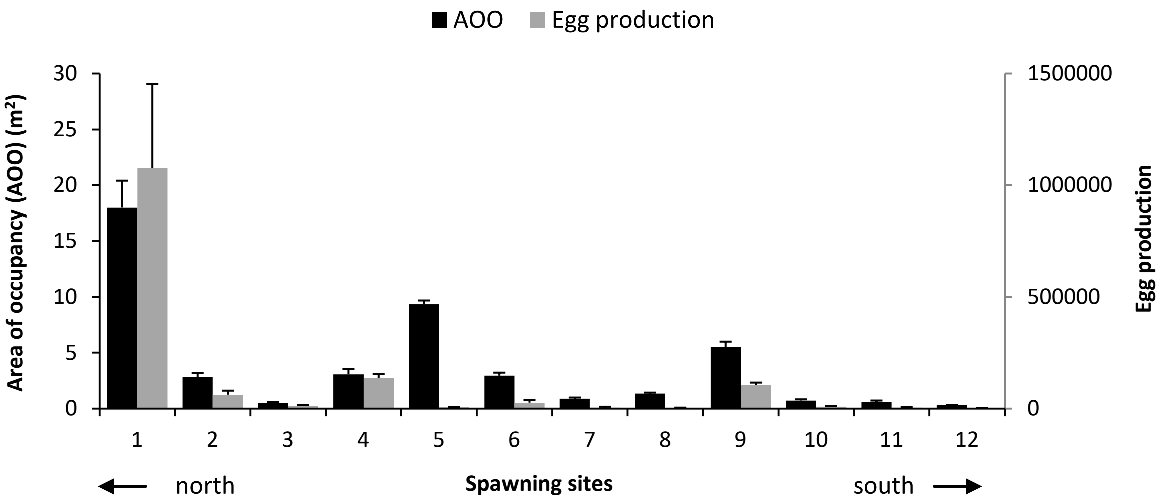

Fig. 7. Area of occupancy (AOO) and egg production of īnanga spawning sites in tributaries of the Arahura River in March 2020. Errors bars are standard error of the mean.

In April, the overall spawning activity was less, with just under 1 million eggs recorded across five sites (Fig. 8). The Flowery Creek site was much smaller than in March (4.1 m^2) and also had lower egg densities resulting in a total of 72,000 eggs. However, the two repeat-use sites in the floodplain island area were both more productive than in March, with 240, 000 and 660, 000 eggs respectively (sites 2 and 3 in Fig. 8). Egg densities at the latter were the highest recorded at any site over both months of the survey, with 9.9 eggs / cm^2. These sites are in the same vegetation patches as March site numbers 5 and 6 (Fig. 7).

Across all five April sites the mean egg density was 3.6 eggs / cm^2, being double the equivalent figure from March. This explains how the much lower AOO in April (only 38% of the March area) was nonetheless able to produce a considerable number of eggs.

A breakdown of egg production across the two months for the four areas described in Section 3.2.1 is provided in Table 4, and a map of the egg production trends in Fig. 9.

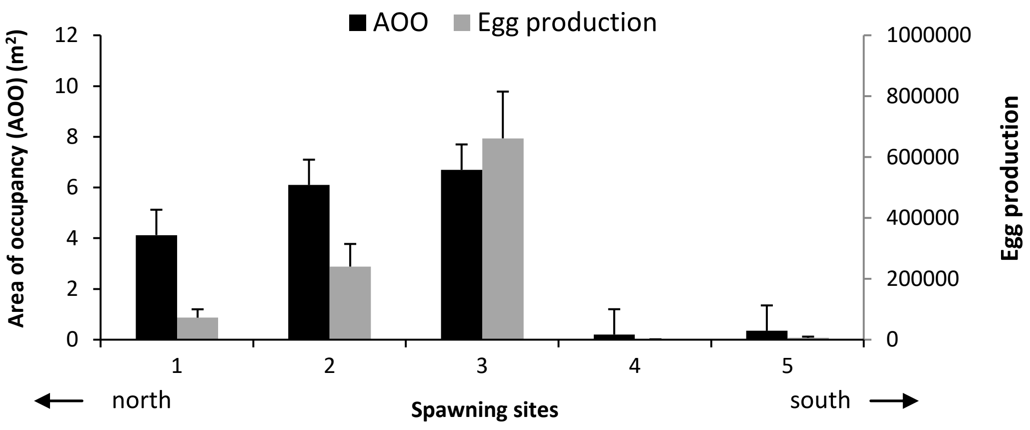

Fig. 8. Area of occupancy (AOO) and egg production of īnanga spawning sites in tributaries of the Arahura River in April 2020. Errors bars are standard error of the mean.

Table 4. Summary of egg production in the Arahura catchment in March and April 2020.

Location	Egg production	
	March	April
northern tidal waterway and Flowery Creek	1139350	72291
wetland area adjacent to Flowery Creek	149750	0
floodplain islands near the main lagoon	37905	901813
Southern tributaries near Greyhound Road	119139	6699
TOTAL	1446144	980802

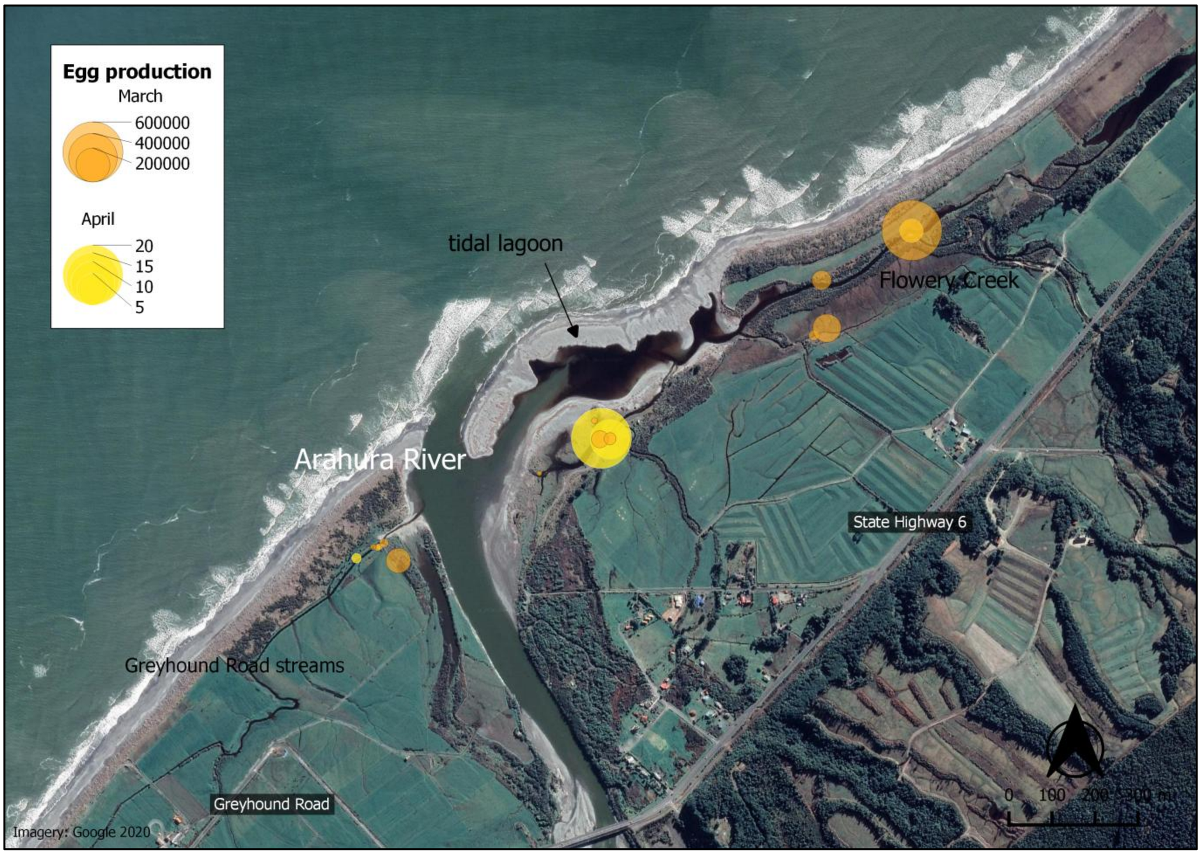

Fig. 9. Map of egg production in tributaries of the Arahura in March and April 2020.

3.3 Storm damage and tidal inundation

In general, the lagoon area contains a complex network of waterways that include established tributaries with base-flows (e.g. Flowery Creek) and remnant channels on the floodplain that are currently cut-off from surface water flowpaths to various degrees (e.g. the small lake on the south bank), but may be reactivated in high water events. Local knowledge sources also indicated that there had been major changes since a series of large storms in December 2019 that caused extensive coastal erosion around the main lagoon. These changes were visualised in a satellite imagery comparison between 2017 and 2020 (Fig. 10).

Some of the key aspects include re-routing of lower Flowery Creek and associated changes to the channel network in the vicinity of the floodplain islands. These changes have created a much more direct connection between lower Flowery Creek and the open water of the main lagoon. Other pre-existing channels and a considerable area of riparian vegetation were also removed by this erosion event (Fig. 10).

During this survey, the observed tidal inundation was generally higher than expected in consideration of the position of fencelines. Peak water heights were sufficient to inundate pasture land in several places. Fig. 2 shows one example from the northern tidal waterway. Other examples were seen in the southern tributaries near Greyhound Round where a series of old side-channels lead to riparian wetlands within pasture areas and are inundated on high tide (Fig. 11).

Fig. 10. Changes to the tidal lagoon system between the summers of 2017 (top) and 2020 (bottom), as seen in satellite imagery. The location of īnanga spawning sites recorded in 2020 is shown for comparison in the lower image. Note changes in connectivity to the Flowery Creek tributaries associated with major erosion and enlargement of the tidal lagoon on its eastern shoreline.

Fig. 11. Two views of tidal flooding into low-lying areas of pasture adjacent to the Greyhound Road on the spring high tide of 11 March 2020.

4. Discussion

4.1 Salinity characteristics

These preliminary observations provide an initial picture of salinity conditions within the lagoon system on typical spring high tides. However, further field measurements would be needed for a comprehensive understanding of salt water intrusion characteristics under various combinations of tidal heights and river flows.

Salt water intrusion patterns observed during this survey is considered to be indicative of a flood-tide directional asymmetry towards the south bank. A relatively large circulation cell (back eddy) was observed within the northern portion of the lagoon which results in strong currents between the floodplain islands. However, these effects were observed in the surface layers only, and may be primarily the result of the relatively high river discharge conditions on the day.

Different patterns are likely to be found with lower river flows. In particular, the distribution of salt-tolerant vegetation suggests that the salt water intrusion in northern lagoon tributaries may reach the Flowery Creek confluence on a regular basis. This is most likely to occur under conditions of a high spring tide and low river flows. Further salinity characterisation is needed to assess variation in these aspects and relationships between the many actual and potential flowpaths within the lagoon area and lower floodplain. Additionally, this short survey has identified the potential for major longer term changes following storm events. These events are likely to require regular reassessment to support river management over time.

4.2 Īnanga spawning activity

Despite some limitations (see section 4.5 below) these results provide useful information on the current distribution of spawning sites in the Arahura catchment. They highlight the important role of tributary streams and side-channels on both the north and south banks for the provision of spawning habitat.

Although high egg numbers were concentrated at a few large sites in this survey, smaller spawning sites were also found in other areas of suitable habitat. Some of these locations may support more spawning under with different hydrological conditions on spawning events, such as those associated with different tidal heights and river flow. Even with the two months of the current survey these effects were illustrated by the location of most egg production having moved from Flowery Creek in March to the floodplain islands area in April.

The influence of sedimentation events on the apparent habitat quality of riparian vegetation around the time of spawning was also noted in this study. The patterns observed suggest that these effects could drive further spatial variability in spawning locations as the fish may be attracted to areas that are less affected in the events.

Salinity effects also have the potential to drive spatial variability in spawning locations. For example, Orchard et al. (2018a) found a strong relationship between the upstream limit of salt water and the upstream limit of spawning in Christchurch waterways, despite that there is no physiological barrier to spawning taking place in entirely fresh water (Orchard et al. 2018a). In this study, the re-routing of Flowery Creek since the December 2019 storms may have generated movement in the preferred locations of spawning due to salinity effects in consideration of the major changes to waterway connections in this location (Fig. 10). As was found in Christchurch following earthquake-induced morphological changes, spawning sites can migrate to entirely new locations following major disturbance vents (Orchard et al. 2018a). Where this occurs, spawning sites may be exposed to new threats relating to human activities in the vicinity of the new sites, and conversely, these movements may also present new opportunities for protection or restoration work.

4.3 Management opportunities

4.3.1 Protection of key sites

This survey found an abundance of good quality habitat within the wider rivermouth system. Although there was some evidence of repeat-use of favourable spawning sites, there were also major differences in the relative contribution of individual sites to egg production on each spawning event. The evidence for storm changes further highlights the need for dynamic management approaches to conservation of the Arahura River, and similar principles are likely to be important in other large rivers and wave-exposed coasts.

To help address these spatiotemporal dynamics there are several remaining unknowns that are a useful focus for future investigations. These include:

- the degree to which adult fish populations move between tributaries and spawning areas;
- whether other spawning sites may be used at other times, and
- variation in the condition and stability of the current sites (as recorded here) in relation to storm and flood events.

The first of these points could be addressed through surveys of the fish population. This is important because there is currently no information on whether populations of adult fish are semi-resident within one area (e.g. Flowery Creek) and therefore may rely on spawning habitat within that area at spawning time. Alternatively, fish may travel between tributaries and across the lagoon system as a whole. If so, they may be less reliant on the availability of spawning habitat within each of the tributary systems.

Resolving these aspects has practical benefits for the management of protected areas and restoration sites. For example, if fish movement is widespread then investing in a few large sites may provide an effective conservation strategy assuming that the mobile fish population will find these sites at spawning time. Conversely, if there is less mobility, it is more important to ensure that habitat is protected and remains available at all of the key tributary waterways that support adult fish.

Further spawning surveys will be useful to establish whether other locations may be used at other times, and to assess variation in the condition and stability of the current sites. It is recommended that such surveys are combined with physical surveys of environmental conditions to enable the identification of contributing factors if changes are found. The monitoring of salinity conditions is one important aspect that will assist interpretation. It is also important to assess the potential for landscape-scale changes at regular intervals, especially after storm events. Suitable techniques include the use of aerial and satellite imagery, or UAV (drone) imagery and elevation models. Information of water heights and river flows is also likely to be useful to aid interpretation.

4.3.2 Restoration opportunities

In general, there is an abundance of good quality habitat for īnanga spawning within the Arahura catchment. This suggests that obtaining further information to help prioritise the protection of existing sites may be beneficial as an investment strategy, as discussed above, and this may largely avoid the need for active spawning habitat restoration. However, it is also important that spawning habitat is integrated within other restoration activities and land-use changes in the area, including potential changes after storms and floods.

There were also a few specific restoration opportunities identified during the field surveys, and these are summarised briefly below. These generally address wider riparian restoration goals (e.g. biodiversity, water quality improvement), but also have the potential to improve habitat for fish.

Willow control and riparian restoration
There is currently a willow infestation in the vicinity of the small lake near Greyhound Road, and close proximity of pasture to waterways in this location (Fig. 12). This area may be a good candidate for riparian restoration work although it is important to note that the willows are currently providing in-stream cover that would be beneficial to the fish population. Restoration work should therefore aim to restore native cover using appropriate species and with attention to the differences required in areas of spawning habitat.

Riparian wetland enhancement
As noted in section 3.3, there are several areas of pasture that appear to be regularly inundated on high tides. In most cases, remnant riparian wetlands are also present at these locations (e.g. Fig. 11). These sites present good opportunities for riparian restoration. Potential benefits include improving water quality through more effective set-backs to high intensity land-uses, and wider biodiversity gains through the enhancement of riparian vegetation.

Floodplain reforestation
Throughout the floodplain there is potential for reforestation activities that could help to improve fish habitat in addition to having many other benefits. As noted above, it is important that reforestation activities are well integrated with the conservation of spawning habitat, and this is assisted by information on the specific locations involved and the monitoring of future change.

Fig. 12. Two views of the small lake that occupies an old flood channel on the south bank.

4.4 Assumptions and limitations

Limitations of this study include egg detection issues that may arise from sedimentation events, as noted in relation to the April survey. Mortality between the date of spawning and the date of survey also introduces variation (Hickford & Schiel 2011b; Orchard et al. 2018b). These affects can have a bearing on the number of sites detected, the observed AOO, and estimates of egg production.

In this case the large size of the search area also made it difficult to ensure that all of the potential spawning locations had been searched with comparable effort, and this is complicated the estimation of water level heights. This is particularly problematic in areas with gentle bank gradients where small changes in inundation levels can translate to substantial horizontal shifts of the high water mark (Orchard 2017).

It should also be noted that the duration of the survey was insufficient for establishing seasonal measures such as total production, or accurate estimation of the peak spawning month. In general, a longer time series of spawning data is needed for these aspects, and to facilitate comparisons between years.

5. Acknowledgements

Thanks to Tihou Weepu at the Department of Conservation for assistance in the field surveys and for liaison with Mawhera Incorporation and Te Rūnanga o Ngāti Waewae. Thanks also to Debra Magner and Nicole Kunzmann at the Department of Conservation for additional project coordination.

6. References

Benzie, V. (1968). Some ecological aspects of the spawning behaviour and early development of the common whitebait *Galaxias maculatus attenuatus* (Jenyns). *Proceedings of the New Zealand Ecological Society, 15*, 31-39.

Department of Conservation and Ministry for the Environment. (2000). *The New Zealand Biodiversity Strategy*. Wellington: New Zealand Government. 144pp.

Dunn, N. R., Allibone, R. M., Closs, G. P., Crow, S. K., David, B. O., Goodman, J. M., . . . Rolfe, J. R. (2018). *Conservation status of New Zealand freshwater fishes, 2017*. *Zealand Threat Classification Series 24*. Wellington: Department of Conservation. 11 pp.

Hickford, M. J. H., & Schiel, D. R. (2011a). Population sinks resulting from degraded habitats of an obligate life-history pathway. *Oecologia, 166*(1), 131-140. doi:10.1007/s00442-010-1834-7

Hickford, M. J. H., & Schiel, D. R. (2011b). Synergistic interactions within disturbed habitats between temperature, relative humidity and UVB radiation on egg survival in a diadromous fish. *PLoS ONE, 6*(9), e24318. doi:doi:10.1371/journal.pone.0024318

McDowall, R. M. (1984). *The New Zealand whitebait book*. Wellington: Reed.

Orchard, S., & Hickford, M. J. H. (2016). *Spatial effects of the Canterbury earthquakes on īnanga spawning habitat and implications for waterways management*. Report prepared for IPENZ Rivers Group and Ngāi Tahu Research Centre. Waterways Centre for Freshwater Management and Marine Ecology Research Group. Christchurch: University of Canterbury. 37pp.

Orchard, S. (2017). *Response of īnanga spawning habitat to riparian vegetation management in the Avon & Heathcote catchments.* Report prepared for Christchurch City Council. 35pp.

Orchard, S., & Hickford, M. J. H. (2018). Census survey approach to quantifying īnanga spawning habitat for conservation and management. *New Zealand Journal of Marine and Freshwater Research, 52*(2), 284-294. doi:10.1080/00288330.2017.1392990.

Orchard, S., Hickford, M. J. H., & Schiel, D. R. (2018a). Earthquake-induced habitat migration in a riparian spawning fish has implications for conservation management. *Aquatic Conservation: Marine and Freshwater Ecosystems, 28*(3), 702-712. doi:10.1002/aqc.2898

Orchard, S., Hickford, M. J. H., & Schiel, D. R. (2018b). Use of artificial habitats to detect spawning sites for the conservation of *Galaxias maculatus*, a riparian-spawning fish. *Ecological Indicators, 91*, 617-625.

QGIS Development Team. (2020). *QGIS Geographic Information System. Open Source Geospatial Foundation Project.* http://qgis.org.