NEW ZEALAND FRESHWATER FISHERIES REPORT No. 133

593

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South Island inanga spawning surveys, 1988 - 1990

ISSN 0113-2504

New Zealand Freshwater Fisheries Report No. 133

South Island inanga spawning surveys, 1988 - 1990

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Report to: Department of Conservation

Freshwater Fisheries Centre
MAF Fisheries
Christchurch

Servicing freshwater fisheries and aquaculture

March
1992

NEW ZEALAND FRESHWATER FISHERIES REPORTS

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ISBN 0-477-08604-7

Edited by:
S.F. Davis

The studies documented in this report have been funded by the Department of Conservation.

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TE MANATU AHUWHENUA AHUMOANA

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SUMMARY

Surveys for inanga (*Galaxias maculatus*) spawning sites in South Island waterways commenced in 1988. Spawning sites were found in 19 catchments, 10 in Westland, six in Canterbury, and three in Nelson.Most surveys by MAF Fisheries ceased in 1990, although further surveys have been carried out by the Department of Conservation. This report collates data available up to the end of the 1991 spawning season.

Spawning zones normally were located in dense bankside vegetation along watercourses, near the upstream limit of the spring tide saltwater intrusion. In modified catchments, inanga eggs usually were found amongst the mass of roots, stems, leaves, and root runners at the bases of introduced grasses. Eggs found in relatively unmodified native vegetation were located in moist leaf litter, trapped and shaded by flaxes, native tussocks, rushes, and the bush subcanopy.

Spawning usually commenced approximately 40 minutes after high water, on ebbing spring tides, and persisted for nearly 40 minutes. In this study, inanga spawned about three days after the new moon, although spawning on full moon tides also has been recorded in other studies.

Spawning site habitats were found to be vulnerable to damage by stock, channelisation, pollution, and a reduction in bank vegetation. It is also suspected, though not proven, that the operation of flood control gates may be detrimental to egg survival. Most spawning areas were already suffering from the adverse effects of some of these impacts, to various degrees, and immediate conservation measures had to be, and were, taken to minimise their effect. Unfortunately, many sites are still vulnerable, and at least one has been totally destroyed by draglining activities. Recommendations are made on how these impacts can be reduced or eliminated, and the spawning habitat restored.

1. INTRODUCTION

New Zealand whitebait comprises the juveniles of five galaxiid species. Of these, the juveniles of inanga (*Galaxias maculatus*) usually form by far the greatest proportion of the whitebaiter's catch (McDowall 1968, 1990), and, for this reason, its life history is relatively well known. Juvenile inanga which escape whitebaiters' nets in spring, grow and mature in coastal rivers and lagoons over the following summer. In autumn, at the time of the full or new moon, ripe (gravid) inanga migrate downstream to spawn in riparian vegetation flooded by the spring tides. It is thought that inanga die soon after spawning. The eggs develop amongst the moist vegetation for 2-3 weeks before becoming resubmerged and hatching on the following spring tide. Larvae are then flushed out to sea on the ebb current, and develop in coastal waters during winter, before migrating up river mouths in spring as whitebait (McDowall 1990). The vast majority of inanga live for one year, although some individuals do not spawn for two or three years.

Widespread concern regarding the general nationwide decline in the whitebait fishery prompted the Freshwater Fisheries Centre (FFC) of MAF Fisheries and the Department of Conservation (DOC) to locate, and, where possible, conserve areas used by inanga for spawning. It was hoped that with increased, or at least maintained, larval recruitment, the whitebait fishery would be sustained and more effectively managed. This is not a new concept. Hefford (1933) highlighted the problem of egg destruction by stock, and recommended fencing off spawning grounds. Since then, research has shown that areas used for spawning are largely reused each autumn by successive generations of inanga (Benzie 1968, Mitchell 1991).

The objectives of this study were to:

(i) discover existing spawning grounds on rivers with significant whitebait fisheries;

(ii) identify biotic and physical factors associated with spawning habitats, the timing of spawning, and fish behaviour;

(iii) advise on how spawning grounds may be located, conserved, and possibly enhanced, to benefit the whitebait fishery.

The FFC undertook this study of the location and periodicity of inanga spawning under contract to DOC, beginning the project in January 1988. Initial surveys were confined mainly to rivers in Canterbury with significant whitebait runs, although an important Westland spawning site on the Hokitika River also was found that year. In 1989, in addition to monitoring east coast rivers, staff from the FFC liaised with staff from DOC's West Coast Conservancy to identify more whitebait spawning sites on the West Coast, and to provide general background information about the biology of the whitebait species. DOC also began field surveys for spawning sites within each of the West Coast Conservancy districts. In 1990, further surveys were carried out both by the FFC and by DOC to discover new spawning sites, and to compare the level of spawning at established sites to that of previous years. Follow-up fieldwork was carried out by DOC and the FFC in 1991, some of which is presented in this report.

A feature of the FFC's role in this project was to transfer research information about whitebait spawning to DOC personnel. As part of this process, a field guide to spawning survey methodology (and aspects of spawning ground protection) was produced by Mitchell and Eldon (1990). The information transfer enabled informed survey work to be undertaken by DOC without the direct involvement of FFC staff. Consequently, with DOC's more numerous and widespread field bases, several river catchments could be monitored simultaneously during the period when inanga spawning was due to occur. This approach provided information on the timing of inanga spawning in relation to tides between river catchments, and even between provinces. However, the FFC, as consultants, retained responsibility for co-ordinating survey work nationwide, collating the data, and presenting the information in a cohesive, integrated form.

2. METHODS

2.1 Timing of Field Surveys

McDowall (1968) showed that gonad maturation in inanga occurs mostly in late summer and autumn, and Burnet (1965) found that their principal breeding migrations into the Waimakariri River occurred in February and March, but that minor migrations extended into April and May. Benzie (1968) recorded spawning in Saltwater Creek occurring as early as January and, on one occasion, as late as May. In light of these findings, spawning surveys began in February of each year, and sometimes ran to the middle of April.

Hefford (1933), Burnet (1965), and Benzie (1968) reported that inanga spawning migrations and spawning occurred within a few days of the spring tide. Therefore our surveys were carried out from about the time of the spring tide to five days afterwards. The dates and times of spring tides were obtained from tidal charts published by the Marine Division of the Ministry of Transport, allowing for daylight saving and location. Even then, local tide height often differed from those published, so calibrated stakes, or other fixed instream reference points, were used as tide datum.

2.2 Survey Techniques

2.2.1 Monitoring the Saltwater Wedge

Previous research (Hefford 1933) reported that whitebait spawning occurs in the vicinity of the tidal saltwater and riverine freshwater junction. At this point, the more dense salt water usually flows under the fresh water, forming a "wedge" of saline water along the river bed, with the point of the wedge directed upstream. As the tide rises, the thin edge of the saltwater wedge intrudes upstream, following the thalweg (deepest part) of the watercourse. Because of the difference in density between fresh and salt water, little mixing occurs, and the boundary between the two remains distinct. This sharp boundary is detectable using a conductivity meter or a salinometer (Fig. 1). In some Westland catchments, sea water and fresh water differed significantly in colour, which allowed observers to detect the saltwater wedge without a salinometer. In catchments with large, shallow, wind-mixed lagoons or estuaries (e.g., Avon/Heathcote Estuary), a quantity of brackish water was pushed upstream on the spring tide, preceding the saltwater wedge for some kilometres.

FFC staff used an uncalibrated, battery-powered conductivity meter (Uniloc model 770 TDS/conductivity analyser), which, although incapable of providing a specific recording of water salinity, was sufficiently sensitive to detect low concentrations of salt. The instrument's sensor probe was attached to the end of a 6 m cable, and lowered into the midstream water from a boat, or bridge, at various points along the river thalweg. When the sensor probe was lowered slowly through the water column, a sudden, full-scale deflection on the meter indicated that the probe was at the top surface of the saltwater wedge. The upstream limit of the wedge could then be determined by further readings along the watercourse. DOC Westland staff used a commercial salinometer (YSI 33 SCT) in much the same manner to provide readings of water salinity in parts per thousand. Where shore access was difficult or impracticable, canoes and small dinghies proved useful for transport.

Having established the extinction point of the saltwater wedge, survey personnel were deployed along the banks, both upstream and downstream of this point. Usually, lack of field staff in relation to the potential size of the spawning area meant that staff were deployed in reaches which were regarded as most suitable, based on the past experience of the survey team leader.

FIGURE 1. Using a salinometer to detect the saltwater wedge.

2.2.2 Identification of Spawning Sites

Prior to survey work, field staff were briefed on visual and aural cues indicative of inanga spawning. Observers looked for large, tight shoals of adult inanga schooling along the banks, which indicated that the fish were intending to spawn, or had already done so. Often these fish would "stream" into niches and other bank features, seemingly to reconnoitre potential spawning locations. Fish ready to spawn did not appear to feed . After the tide turn, ripe fish schooled into the flooded emergent vegetation, and, with keen observation, these fish could be seen amongst the bases of the riparian grasses and rushes. After intensive spawning, discharged milt tended to cloud the water amongst the emergent vegetation, but less active spawning often failed to produce this characteristic. Birds (ducks and herons), eels, trout, and even stoats, were observed feeding on spawning inanga. Inanga eggs, and, occasionally, entangled adults, were found amongst the bases of riparian vegetation after the tide had receded.

Spawning inanga disturb the water surface along the margins, and the resultant faint, clear, pattering sound is quite audible some distance away, particularly when there are large numbers of fish involved. Often, this characteristic sound was the first evidence that whitebait were spawning in the vicinity. The distinctive sound of eels "slurping" as they fed on inanga also may be heard.

2.2.3 Data Collection from Spawning Sites

While spawning was still taking place, an effort was made to establish the extent of the spawning zone (i.e., the boundaries at which little or no further spawning occurred). In practice, it was easier to demarcate spawning zones from the activities of the spawning fish, rather than by attempting to establish the distribution of inanga eggs in thick vegetation at a later date. Spawning zones were marked out by stakes, photographed, egg densities estimated, and botanical surveys undertaken. Field notes were made on the timing of spawning in relation to the tide height and cycle, and the distance and direction of the spawning zone in relation to the saltwater wedge. Also recorded were information on the physical relief of the spawning zone, and the degree of access that was available to spawning inanga.

Botanical surveys were carried out at some inanga spawning sites by the DSIR, including the Avon River in Canterbury, and eight catchments in Westland (the Grey, Hokitika, Poerua, Wanganui, Waitangitaona, Makawhio, Manakaiaua, and Turnbull Rivers (Meurk undated a,b).

3. RESULTS

Inanga spawning surveys commenced in January 1988, with a survey of spawning sites on the Ashley River in Canterbury. Overall, at least 149 spawning surveys were conducted over four years in 24 catchments, during which 119 spawning sites were discovered from 19 catchments (Appendix I and Fig. 2). Of these field surveys, at least 72 failed to find spawning grounds or egg deposits (Appendix I). Clearly, unknown local factors may influence the onset and periodicity of spawning, which is why local knowledge proved to be important in the successful location of spawning grounds.

The common names of plants identified at spawning grounds are given in the text, and their botanical names are provided in Appendix II. Vegetation profiles were constructed at some sites, and these are referred to in thee text and depicted in the appendices.

3.1 Study Areas and Field Results

The following sections provide brief physical catchment descriptions, and give the field results from surveyed catchments. Many of the physical descriptions have been gleaned from previous FFC reports (e.g., Davis 1987, Kelly 1988). Detailed field data are summarised in Appendices III and IV.

3.1.1 Ashley River Catchment

The Ashley River rises from the Puketeraki Ranges, and flows for 90 km before discharging into Pegasus Bay, 30 km north of Christchurch. In the lower reaches, the mainstem follows a braided course, although the adjacent farmland is protected both by thick willow vegetation and by levees on each side of the river floodplain. Numerous, small, spring-fed tributaries enter the Ashley mainstem and lagoon from the south bank, firstly flowing slowly through pasture, and then through salt-tolerant rushes near the estuary.

The watershed of the Ashley River tributary, Saltwater Creek, arises in the foothills of Ashley State Forest, but, for almost all its 13 km length, the stream meanders gently through farmland, before flowing into the Ashley River lagoon.

An officially unnamed, spring-fed stream, known by FFC staff as "Benzie's Creek", is a major tributary of Saltwater Creek. Benzie's Creek is lined with willows and pasture grasses for most of its 4 km length, but 300 m above the confluence with Saltwater Creek, the stream borders a pig farm. It enters the Saltwater mainstem approximately 500 m upstream of Ashley lagoon.

Spawning grounds in the Ashley catchment were found at three locations: Benzies's Creek, along the mainstem of Saltwater Creek, and in lowland tributaries of the Ashley River (Fig. 3).

3.1.1.1 Results from Benzie's Creek

Spawning was recorded from Benzie's Creek on 22.01.88 and on 19.03.88, with more spawning recorded on the latter date. In total, six spawning zones were identified, with a combined length of 42.6 m. Spawning commenced about 10 minutes after high water, and proceeded for about 30 minutes. Almost all the spawning sites were on the true right bank, just below the spring tide saltwater wedge, although the surface waters were fresh. Spawning did not occur amongst the sparse riparian vegetation under willow trees, the lush, dense, pasture grass appearing to be preferred. Small numbers of eggs were found on the stems of rushes, and at the bases of toetoe (Fig. 4a). A vegetation profile depicting one of these sites is given in Appendix V.

3.1.1.2 Results from Saltwater Creek

During the evening spring tide of 22.01.88, with high water at 2100 h NZDT (New Zealand Daylight Saving Time), a reconnaissance of spawning sites along the mainstem of Saltwater Creek was undertaken. When very weak spawning activity was heard along the true left bank of the west branch at approximately 2200 h (NZDT), this location was marked for further examination in daylight. Examination at low tide on 26.01.88 revealed only two small egg concentrations, although on the opposite bank, eight egg concentrations were discovered extending over a distance of 149 m. All eight spawning zones were on a gently sloping shelf at the confluence of the west branch and the mainstem. Vegetated with grasses, flax, and raupo, the shelf was protected from sheep grazing by gorse thickets. Surprisingly, a live, ripe male inanga was found amongst thick grass at this location. Crabs also were observed. Elsewhere, where gorse protection was absent, riparian grasses were grazed to a stubble, and were devoid of eggs. With the exception of one site, all spawning sites were approximately 130 - 280 m downstream of the spring tide saltwater wedge. The most upstream site was 47 m below the maximum penetration of the saltwater wedge.

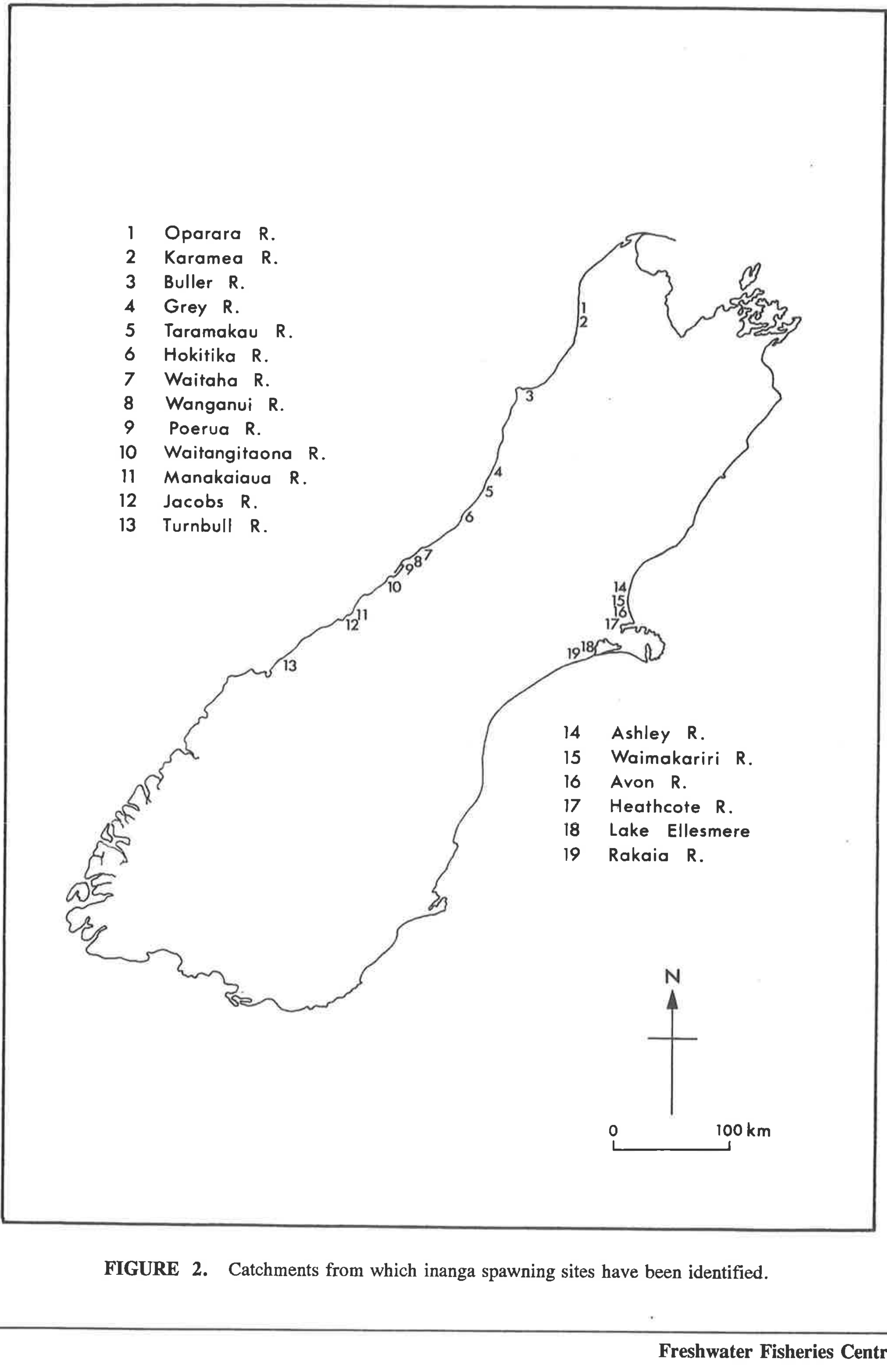

FIGURE 2. Catchments from which inanga spawning sites have been identified.

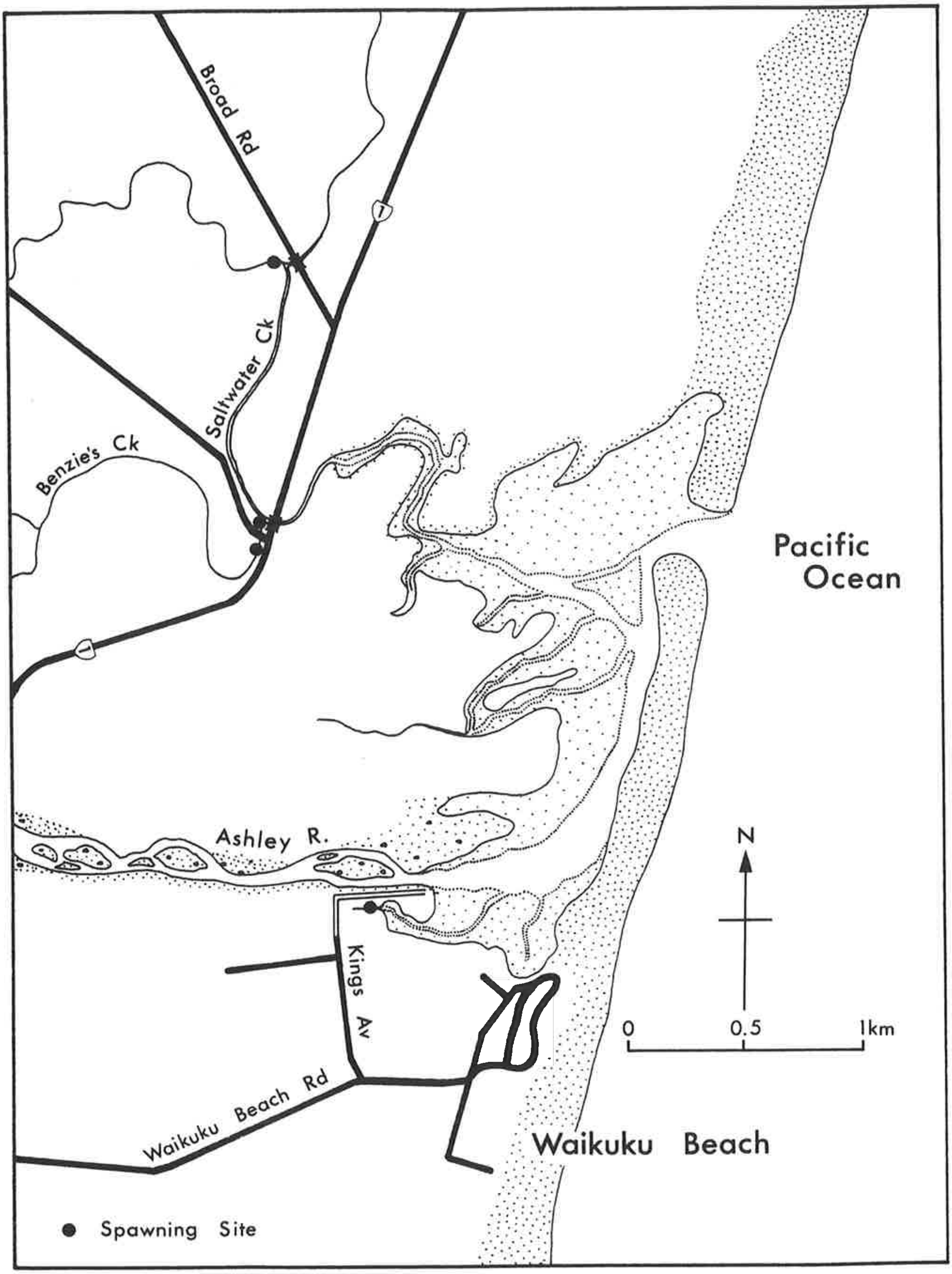

FIGURE 3. Inanga spawning sites in the lower Ashley catchment.

FIGURE 4a. Inanga eggs adhered to leaf litter and basal roots of toetoe at Benzie's Creek, Ashley River catchment.

3.1.1.3 Results from an unnamed Ashley tributary

Very active spawning was noted in a narrow tributary draining into the Ashley lagoon on 19.03.88, one day after the new moon, and 45 minutes after high tide (Fig. 4b). Spawning took place over 13 m of the stream bank, and was observed for nine minutes, although it is likely that spawning had occurred for some time before arrival at the site. Spawning zone vegetation was luxuriant, 1-m-high pasture grass (Appendix VI), the downstream limit being associated with the proliferation of three square, a salt-tolerant sedge. There was a strong ebb (surface) current of approximately 0.3 m/s whilst spawning was taking place. Salinity measurements taken during spawning indicated that the saltwater wedge was lying over the stream bed at the spawning site, although surface water was fresh.

3.1.2 Waimakariri River Catchment

The Waimakariri River rises on the eastern slopes of the Southern Alps, flows 137 km to the sea, and has a catchment area of about 3625 km^2. In the lower reaches, 2.5 km from the mouth, the Kaiapoi River enters.

The Kaiapoi River rises just north of the Waimakariri River, and flows placidly through pasture for about 9 km, before its confluence with the Waimakariri mainstem. The Kaiapoi receives effluent from a local abattoir and other industrial sources associated with the township of Kaiapoi. An understorey of grasses, rushes, and mosses, combined with a canopy of thick willow, vegetate the southern bank, whereas the grassed and mown northern bank borders a public domain and residential properties. The location of spawning sites in the lower Waimakariri River is shown in Figure 5.

The Styx River rises from springs at the northern outskirts of the city of Christchurch and flows 21 km through both horticultural and agricultural land before discharging through tide gates into Brooklands (Waimakariri) lagoon. Below the tide gates, about a kilometre from the mouth, there is an extensive area of wetland, comprising salt-tolerant sedges and luxuriant *Festuca* grass. The tide gates close on spring tides.

3.1.2.1 Results from the Kaiapoi River

On the spring tide of 20.03.88, two days after the new moon, the Kaiapoi River was surveyed for inanga spawning sites. Salinity readings indicated that the

FIGURE 4b. A slow-flowing stream draining into the Ashley lagoon. Spawning was restricted to the tall fescue in the foreground. The salt-tolerant rush three square was not used for spawning.

saltwater wedge extended approximately 920 m upstream from the Kaiapoi River mouth. No evidence of spawning was found on the north bank, but sounds consistent with inanga spawning were heard on the south bank approximately 20 minutes after high water, 25 m below the limit of the saltwater wedge. Later that day, after the tide had fallen, eggs were found adhering mainly to moss filaments and partly to rush stems over a distance of 4 m (Fig. 6). The moss formed a thick, carpet-like layer of 30 mm, overlying sand. The following month, on the spring tide of 17.04.88, the south bank was investigated for further whitebait spawning. Spawning was observed in a narrow creek flowing into the mainstem, 20 m downstream of the mossy spawning zone. This creek was bordered by thick pasture grass, which provided ideal spawning habitat.

3.1.2.2 Results from the Styx River

Salinity readings at the tide gates showed that they effectively prevent the saltwater wedge intruding further upstream. When the horizontally-hinged gates close, fresh water backs up behind them for about two hours, before they re-open on the falling tide (FFC unpublished data). Despite extensive survey efforts over three seasons to locate inanga spawning grounds in this catchment, only one tentative indication of spawning has been recorded. The site was downstream of the tide gates in a narrow, grass-lined tributary.

3.1.3 Avon River Catchment

The Avon River originates from a number of springs in the northern and western suburbs of Christchurch city. Flowing for approximately 22 km in a generally eastward direction, flow is augmented by the municipal stormwater drainage system before discharging into an extensive estuary east of the city. The river is channelised, and an increasing proportion of the bank margin is stone walled. Riparian vegctation largely comprises mown grasses and exotic trees, although remnants of native vegetation persist in the lower reaches.

Inanga spawning ground surveys began on the Avon River during 1988 when the lower river, downstream of Kerrs Reach, was surveyed by boat (Fig. 7). Salinity

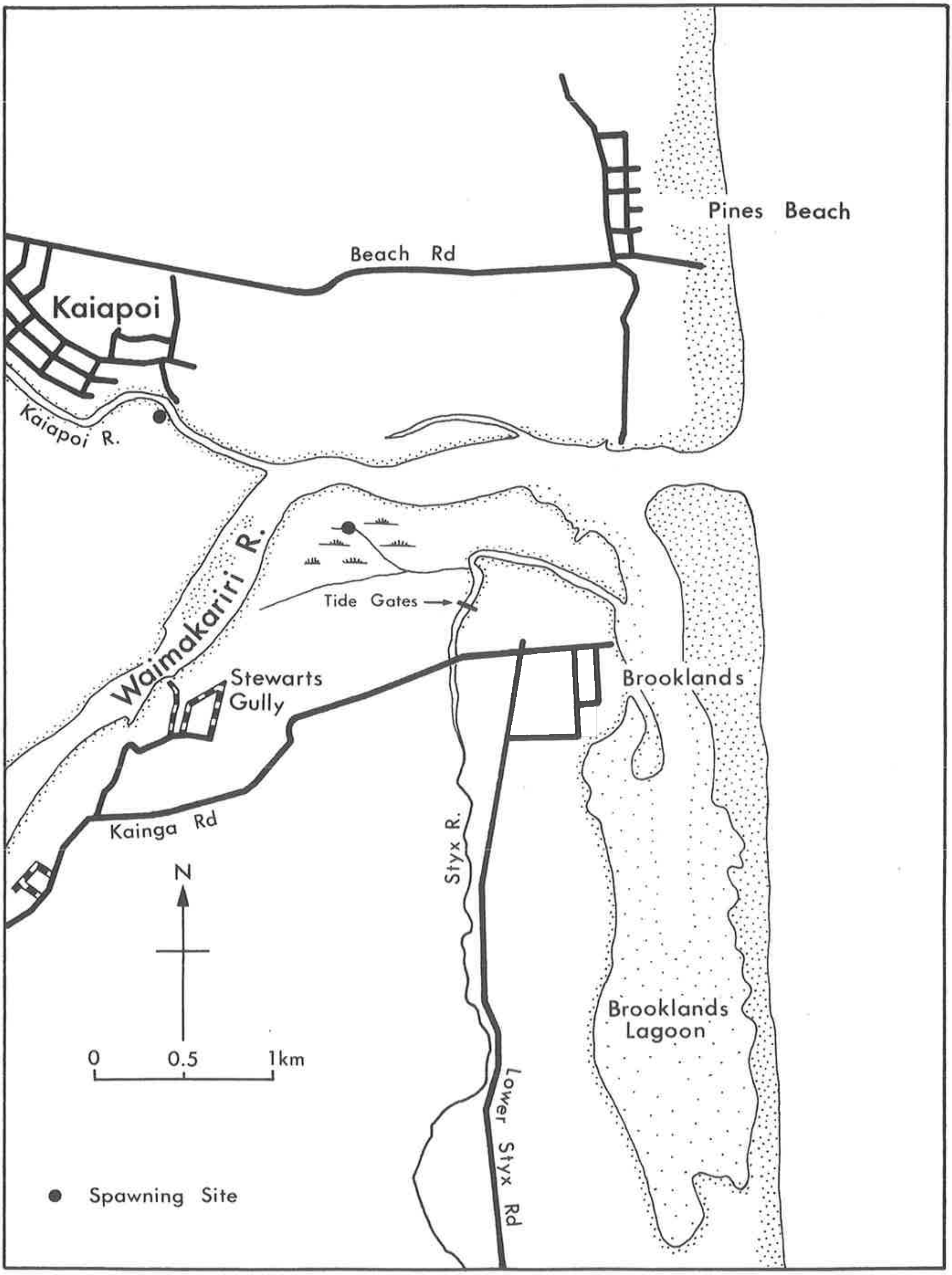

FIGURE 5. Inanga spawning sites in the lower Waimakariri catchment.

FIGURE 6. Mossy spawning area on the Kaiapoi River, a tributary of the Waimakariri River. Eggs were identified from the area between the two stakes.

measurements on a 1988 spring tide indicated that brackish water reaches Avondale bridge, but considerable mixing occurs below this point, with little stratification of water salinity.

A large school of inanga was observed on the high tide at Avondale bridge on 10.04.89, 55 minutes after high water. On 21.04.89, eggs were found both upstream and downstream of the bridge on the true right bank. Eggs were located on the basal stems of a range of tall grasses and rushes: bergamot mint, tall fescue, jointed rush, New Zealand rush, and umbrella sedge (Meurk undated a, Appendix VII). Upstream of the bridge, a few eggs were located around the base of pukio (tussock sedge). The downstream spawning zone covered a strip 40 m x 0.3 m, approximately 0.2 m above the high tide mark. Although the true left bank was searched for eggs, none were found at this steeper, more eroded location.

The reach was resurveyed in February the following year (27.02.90), to clarify when spawning took place in relation to the tidal cycle. At this time, spring tides were at night, and 35 minutes elapsed after high water before spawning activity was heard along the true right bank. An inspection of the area by torchlight revealed eels swimming amongst submerged grasses, and inanga could be heard as they spawned under a canopy of vegetation. Spawning was concentrated at eight locations along a 40 m section of this reach, although no milt was observed and spawning was clearly limited.

Two surveys of the Avondale site were carried out in May 1991, but there were no indications of spawning and no eggs were found. It is possible that spawning took place earlier in the season.

3.1.4 Heathcote River Catchment

The Heathcote River rises from springs in the vicinity of Wigram airbase, but also receives flow from Cashmere Stream which drains the Hoon Hay valley south-east of Christchurch. While meandering through the city for about 17 km of its 20 km length, the river receives waters both from stormwater and from industrial discharges before entering the Avon-Heathcote estuary. Similar to the Avon, the Heathcote is regularly weed dredged and its banks are shored. The river banks are sown with pasture grass, and consolidated with mature willow, except in the lower reaches around Ferrymead, where salt-tolerant reeds dominate. The City Council is revegetating portions of the riparian border with native species.

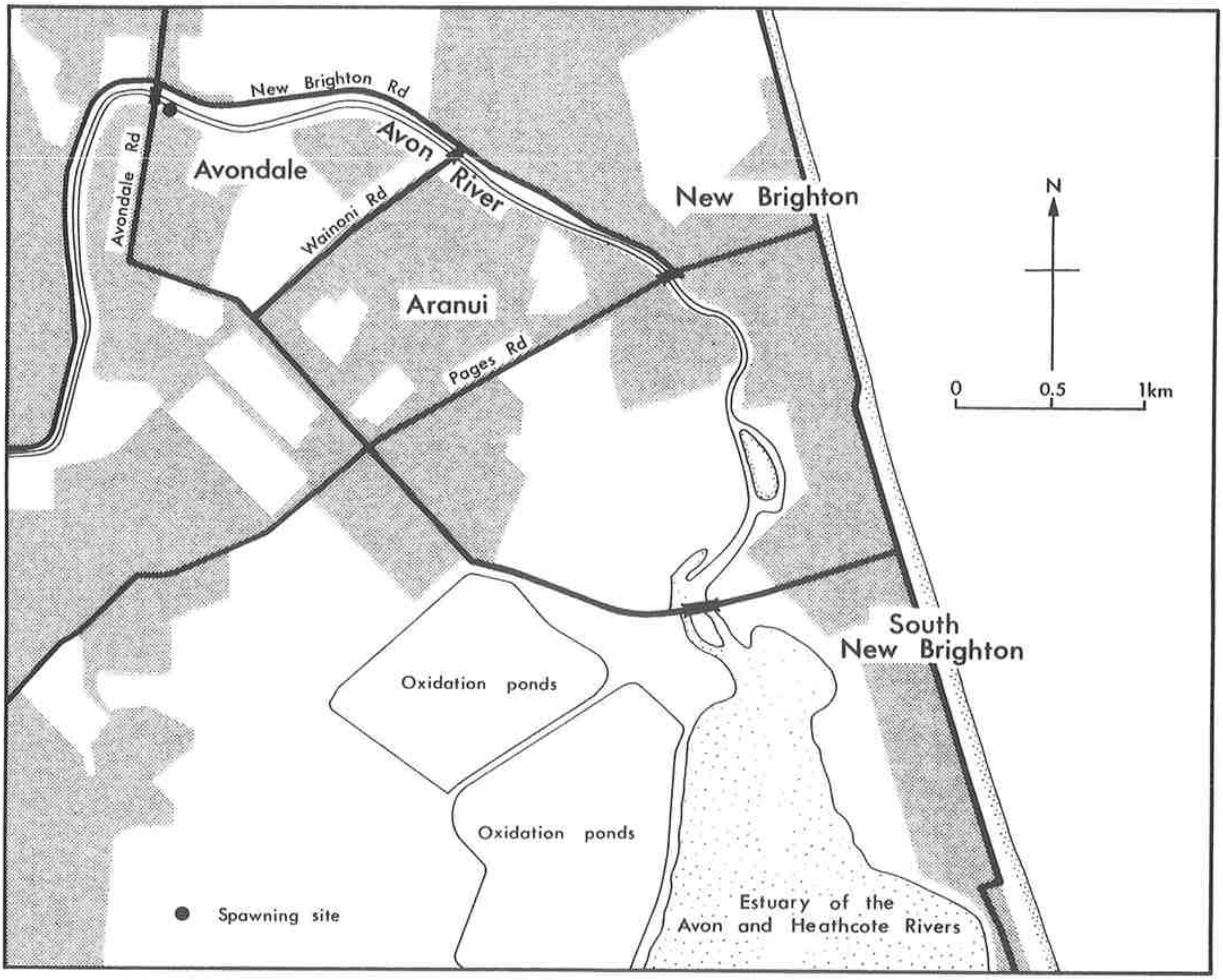

FIGURE 7. Location of the inanga spawning site at Avondale bridge on the Avon River.

On the spring tides of 09.02.89 and 10.02.89, inanga were seen swimming amongst riparian musk vegetation just upstream of Wilsons Road bridge (Fig. 8). Captured specimens were running ripe, although spawning was not observed. On 11.02.89, five days after the new moon and one hour after high spring tide, active spawning was observed at this location, although it was too dark for field data to be recorded.

A later search (15.02.89) amongst the densely grassed, but steeply banked, river margins, revealed that the spawning zone extended from approximately 20 m upstream of the bridge to 70 m downstream on the true left bank, and 25 m downstream on the true right bank. Egg concentrations were found on the root mat of pasture grasses and rotting detritus, on the stems of emergent monkey musk (Fig. 9), and adhered directly to vertical earth banks. Many eggs also were found close to the water line at low tide, and thus were submerged on normal high tides. These spawning zones were well upstream (1.5 km) of saltwater penetration (G.A. Eldon pers. comm.). The steepness of the bank profile discouraged regular, close, grass mowing by the Christchurch Drainage Board, or trampling by pedestrians, and thus humus layer humidity and inanga egg viability were maintained. In late February 1989, a survey was carried out to coincide with the full moon tides (full moon was on 21.02.89), but no spawning activity was observed.

In early March 1989, the Christchurch Drainage Board cut the steep riparian vegetation upstream of Wilsons Road bridge to a sparse stubble, and effectively destroyed this reach as an inanga spawning ground for the April spring tides. However, spawning did take place in the musk bed downstream of the bridge on 11 and 12 March, four and five days, respectively, after the new moon, and about 60-105 minutes after high tide. Unlike the upstream site, the vegetation in this area had been left uncut. There was some predation by

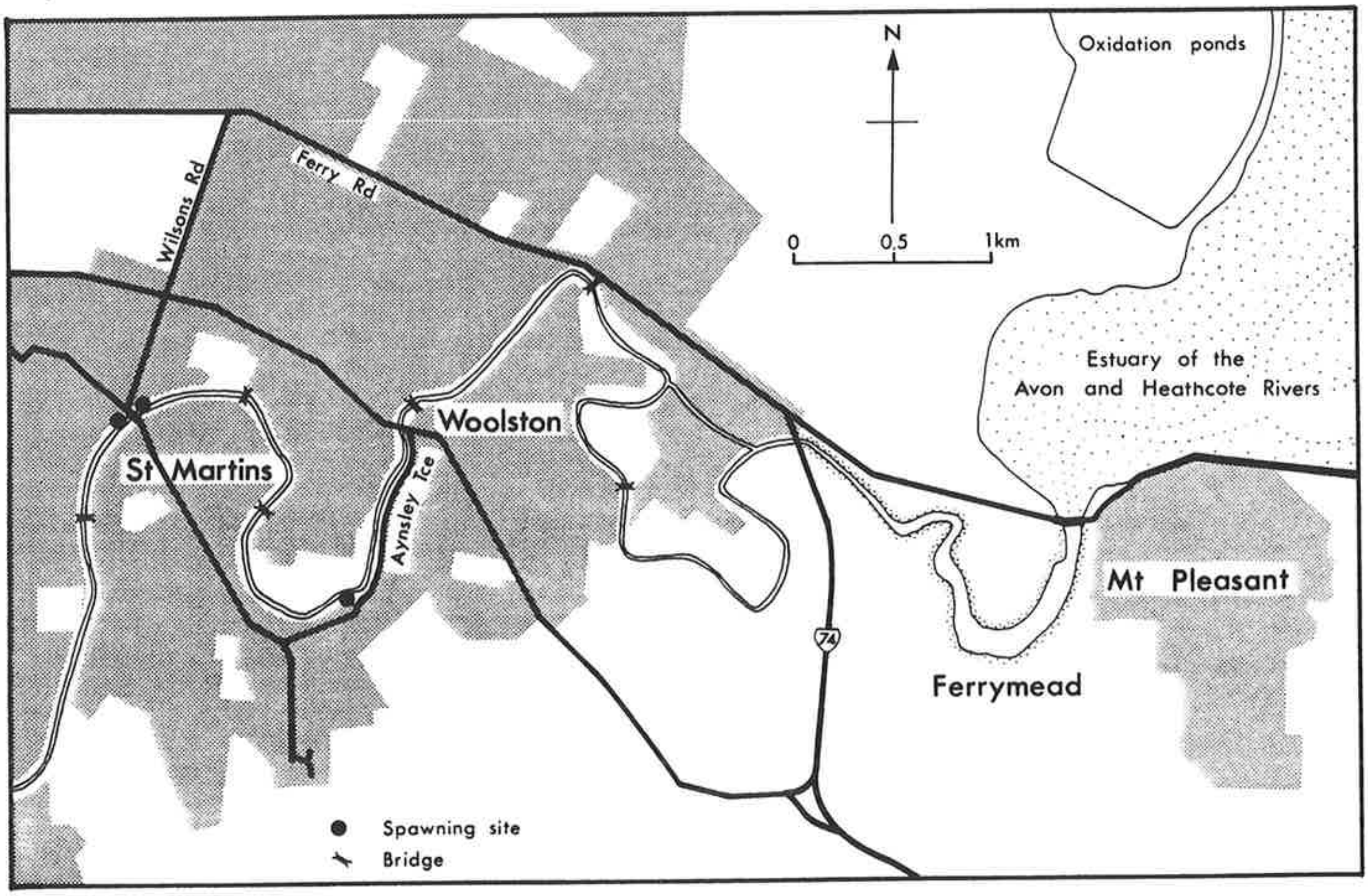

FIGURE 8. Location of inanga spawning sites on the Heathcote River.

ducks on adults, and probably on eggs too. This reach has been surveyed a further 10 times in 1990 and 1991, but no spawning has been recorded.

A spawning area near Aynsley Terrace was discovered on 19.04.91 in a reserve set aside for native revegetation (Fig. 8). This reach was surveyed two years previously, prior to inception of the revegetation project, and no spawning activity was observed. At that time, the riparian vegetation comprised willows and mown grass banks. Spawning began approximately 45 minutes after high water, and ceased at the most downstream of the four sites after 25 minutes. The four spawning sites were distributed over 100 m of unmown stream bank, thickly vegetated with broadleafs, tall fescue, yorkshire fog, buttercup, and clover. Approximately 5 m from the water's edge, saplings of manuka, kanuka, kowhai, and podocarps had been established, and flaxes and sedges had been planted in the vicinity of a spring head. At the time of spawning, salt water was barely present (1 ppt when measured from the river bank). Spawning activity was generally light, with barely visible traces of milt discolouration in the water. When the tide had fallen sufficiently, a search for eggs revealed that egg densities were highest at the most upstream (site 4) and the most downstream (site 1) sites. Site 4 was at the confluence of the mainstem and a side channel, whereas site 1 was a section of slumped bank, 2 m long. Sites 2 and 3 were small (1 m), and had relatively low densities of eggs.

The following day (20.04.91), this reach was resurveyed, and inanga were observed amongst the vegetation at site 2, 15 minutes after high water, and then at site 1, 10 minutes later. Spawning at site 1 was still taking place 55 minutes after high water. Owing to severe water discolouration caused by overnight rain, it was not possible to establish if large shoals were present, although the very low level of spawning may indicate that most of the spawning had taken place on previous spring tides.

3.1.5 Lake Ellesmere Catchment

Lake Ellesmere is a large, shallow, coastal lake, fed principally by the Selwyn River, but also by ground water and springs in the vicinity. Lake area is highly dependent on water levels, and although Hobbs (1947) estimated the average surface area to be 25 900 hectares (259 km^2), it is probably much smaller now. Lake level is controlled by bulldozing an outlet to the sea when

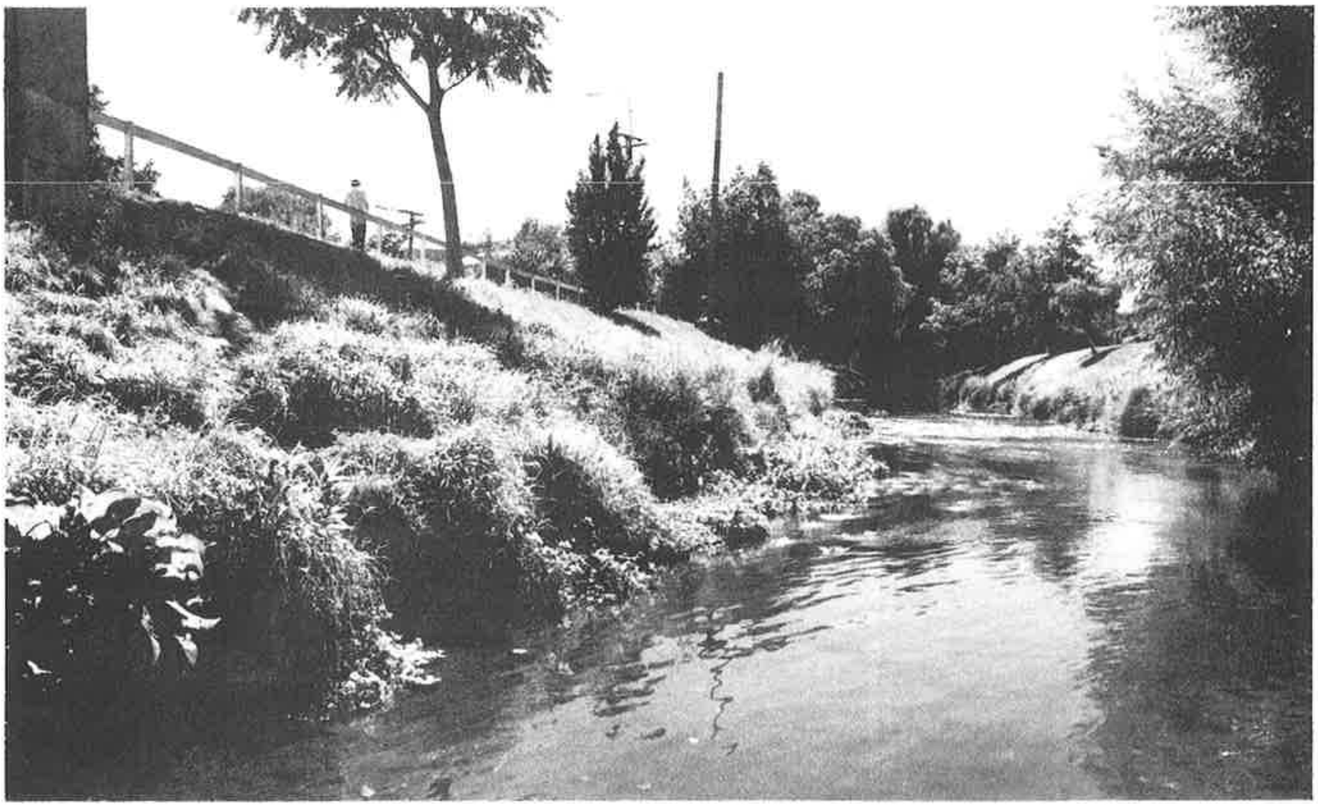

FIGURE 9. High inanga egg densities were found amongst the emergent musk (centre of photograph) downstream of Wilsons Road bridge, Heathcote River.

water depths fall outside predetermined levels set by a National Water Conservation Order. The water is brackish, and a degree of seawater diffusion occurs under the sand bar separating the sea from the lake. Further, the effect of wind push has an important, though erratic, influence on depth.

Waikewai Creek is a small, spring-fed stream which flows into Lake Ellesmere near its southernmost tip (Fig. 10). Approximately 1.3 km from its swampy source, the creek flows sluggishly through pasture, but, near its outlet, the inaccessible east bank supports thick, emergent raupo vegetation, which intrudes onto the opposite bank near the stream mouth. The west bank comprises pasture grass interspersed with tussock and broom, and is subject to light grazing by stock. Some fencing and thick broom has limited stock access to the occasionally slumped and shelved true left bank.

Reports of inanga spawning around the lake margins and tributaries have been received by the FFC from local eel fishers. A foot survey of Waikewai Creek and the surrounding lake edge was carried out on 14.03.89. The lake edge proved to be unsuitable, largely owing to stock damage, although a substantial area of inanga eggs was discovered along the true left bank of Waikewai Creek. Egg concentrations were high, albeit patchy, and deposited on the basal roots, or detritus, of pasture grasses, emergent musk, or raupo (Fig. 11a). In contrast, the true right bank vegetation consisted wholly of dense, emergent raupo, and largely appeared to be unused for spawning. Further searches for eggs between spring tide periods indicated good survival, with many eggs having "eyed" in a week. Eggs also were found on the bare earth, and these were thought to have washed off nearby vegetation.

The following month, an effort was made to establish the spawning times of inanga in Waikewai Creek. On 10.04.89, four days after the new moon, large shoals of mature fish were seen in the lower reaches, and, 50 minutes after high water, a small number (20-30) of fish spawned, ceasing after 45 minutes. The tidal peak was 3 h 10 minutes after high water at Rakaia. Spawning was confined to detritus amongst the emergent raupo near the lake edge and ceased 95 minutes after high water.

Shoaling fish also were observed on 11.04.89, but strong southwest wind and rain disrupted the normal tidal cycle, to the extent where normal high tide water levels were 200 mm lower, and known spawning areas were left stranded. On 12.04.89, sparse, but widespread, spawning occurred over 65 m of the true left bank, in five different locations. Water levels were about 40-50 mm below the tide on 10.04.89, and

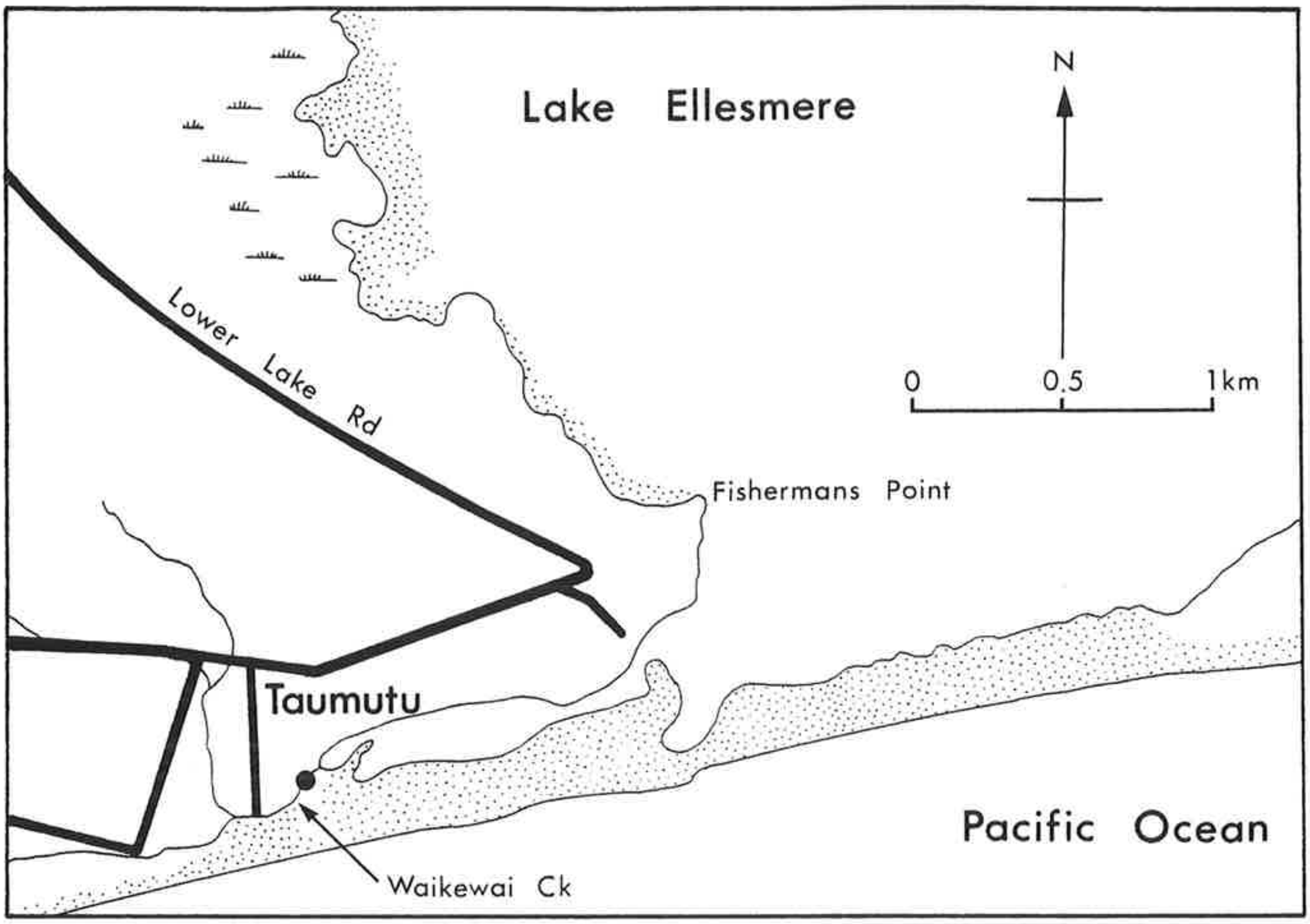

FIGURE 10. Spawning site on Waikewai Creek, a tributary of Lake Ellesmere.

spawning had already started upon arrival (75 minutes after high water), and was still occurring in some locations two hours later, when the survey finished. It was noticed that the stream level was rising and falling by 3-4 cm over the survey period.

During May 1990, Waikewai Creek was catastrophically dredged with a mechanised trenchdigger, totally destroying the riparian and macrophyte vegetation (Fig. 11b). In this state, it is very unlikely that successful spawning will occur at this location for several years.

3.1.6 Rakaia River Catchment

The Rakaia River has a length of approximately 140 km, and rises from the Lyell Glacier on the eastern side of the Southern Alps at an altitude of 1200 m. The river's major tributaries above the gorge (Lake Stream, Mathias, Avoca, Wilberforce, and Acheron Rivers) drain most (90%) of the total catchment area of 2850 km^2. Below the gorge, the river receives mainly small, spring-fed streams, and flows 61 km across a wide, extensively braided, shingle bed, with a relatively uniform gradient, before entering Rakaia lagoon. The lagoon also receives direct input from two small, spring-fed tributaries (Mathias and Boat Creeks) (Eldon 1983). Historically, Mathias Creek was used for inanga spawning, although the land east of the lagoon has since been pastoralised and these streams are now grazed to the water's edge.

Considerable efforts were undertaken to locate the inanga spawning grounds for the Rakaia's recreational whitebait fishery over three successive seasons (1988, 1989, 1990). However, it was only during the last of these that spawning sites were discovered in tributaries discharging into the lagoon.

3.1.6.1 Results from Boat Creek

Spawning was recorded from Boat Creek (Fig. 12), on 28-29.03.90, one and two days, respectively, after the new moon. At 40 minutes after high tide, spawning commenced at the mouth of Boat Creek along the south bank. At this point, the bank forms a grassed, shallow terrace which floods on the spring tide to a distance of 15 m from the normal water's edge, and 20 m along the

FIGURE 11. Lower spawning site on Waikewai Creek, Lake Ellesmere, (a) prior to dredging, and (b) in May 1990, after dredging.

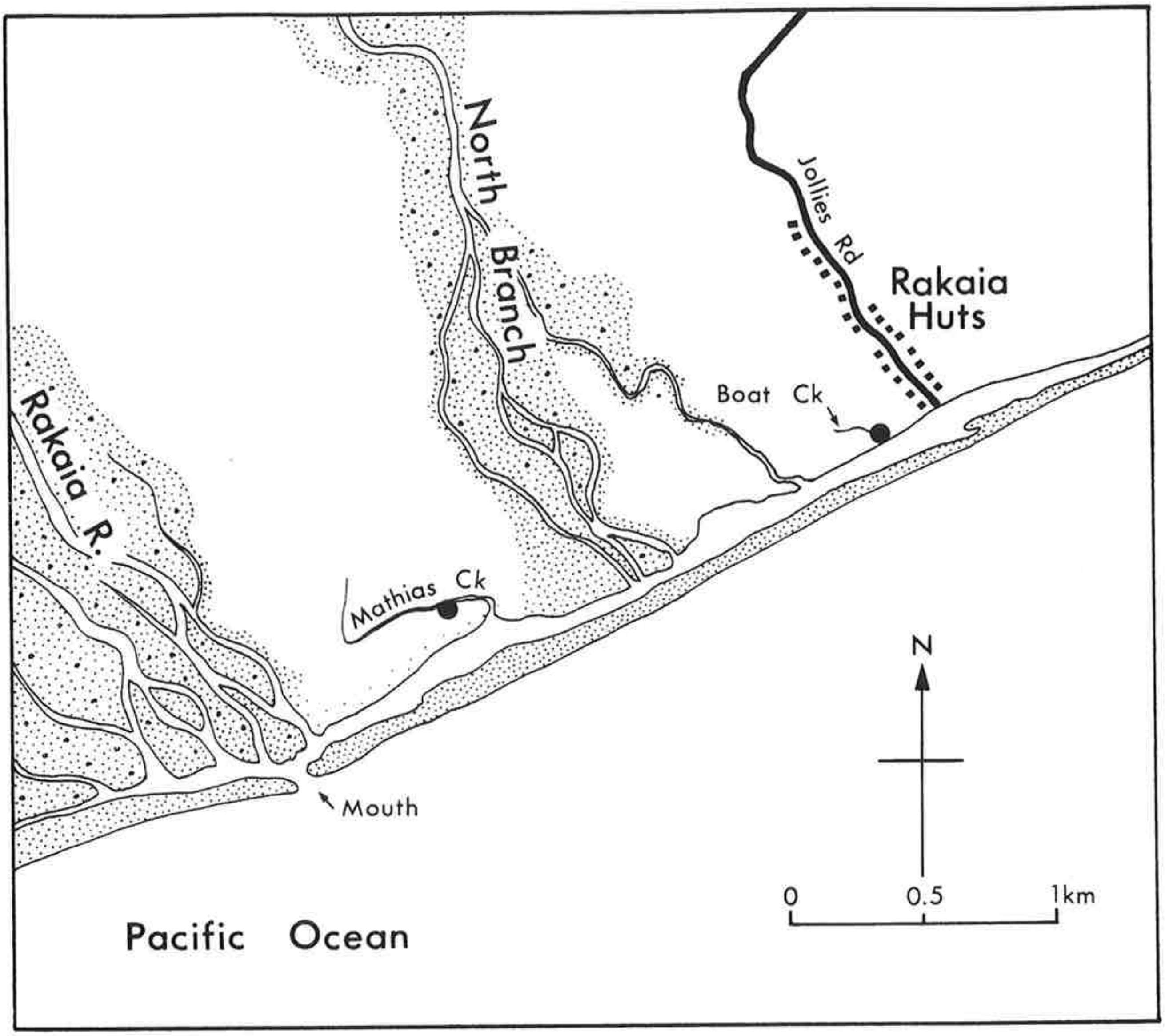

FIGURE 12. Inanga spawning sites in tributaries of the Rakaia River lagoon.

bank. An ebb flow of 0.03 m/s was noted at the time. Three other south bank spawning zones, and three small spawning sites on the north bank also were discovered. South bank spawning sites were punctuated by areas of gorse and blackberry which, on the spring tide, extended to the water's edge. However, on the north bank, half-submerged flax and stunted willow dominated the riparian vegetation, and spawning zones were limited to small grassed sections between them. A barbed-wire fence prevented cattle access to most of the lower reaches of the south bank, whereas an electric fence on the north bank provided protection for those spawning sites. Inanga were still spawning 65 minutes after high tide, when the ebb tide had increased to about 0.07 m/s, and the water level had dropped 0.1 m from the high tide level. Approximately 95 minutes after high tide, spawning had ceased, and large schools of spent inanga were observed swimming downstream, out of Boat Creek towards the blind end of the lagoon, away from the Rakaia River mouth.

3.1.6.2 Results from Mathias Creek

Spawning sites on Mathias Creek were discovered on 28.03.90, but the activity was less intensive, and the sites smaller, than those discovered on Boat Creek. No spawning took place on 29.03.90. Site vegetation was similar to that on Boat Creek, with thick bankside grasses, but gorse and blackberry were absent.

3.1.7 Oparawa River Catchment

The Oparawa River rises from Bald Knob (elevation = 1281 m) in the Fenian Range north of Karamea, and flows for 12 km in a mainly steepsided, forested valley. Downstream of the valley, the river flows 5 km across a pastoralised, extensively drained plain before discharging into a sizable estuary. There are some remnant, draglined, wetland areas, and several dune lakes north of the estuary.

Inanga spawning was observed by DOC staff on 30.03.90, three days after the new moon, in farm drains discharging into the Oparara mainstem. Further sites were found in swampland drains north of Oparara lagoon (Fig. 13). The land owner claimed that inanga had been "active" since December 1989, with activity peaking in February 1990.

3.1.8 Karamea River Catchment

The Karamea River rises near the Wangapeka saddle, and drains both the Arthur and Tasman Ranges. With a catchment area of 1242 km^2, and a mainstem length of 80 km, the Karamea is a major West Coast river. The higher reaches are particularly scenic, albeit rugged, with many rapids, before the river flows through a narrow gorge and over a small coastal plain. Near the mouth, a large lagoon drains lowland pakihi. The southern lagoon, Kongahu Swamp, is considered to be an important whitebait spawning area. The river discharges into the large Otumahana estuary, before entering the sea (Fig. 13).

3.1.8.1 Results from Baker Creek

DOC staff found inanga spawning grounds on Baker Creek, a tributary of the Karamea River, on 10.03.89, two days after the new moon. Spawning commenced along Baker Creek, at the top of the tidal reach, 75 minutes after high tide. However, the following day, spawning had already commenced only 10 minutes after high water, and stopped about 110 minutes after high tide, when inanga were seen swimming downstream from the spawning site. Spawning was reported as very active at its peak, and occupied 60 m of the banks on both sides of the stream. Spawning was recorded from this site, and sites further downstream, for two more days, although the number of fish and extent of spawning activity decreased (Appendix IV). On the last day upon which spawning was recorded, spawning commenced six minutes after high tide, but was limited to two small downstream areas.

3.1.8.2 Tributaries of the Otumahana Estuary

In 1990, spawning was very limited in Baker Creek, with only small patches of eggs being found during March at the same location where active spawning took place in 1989. However, new spawning areas were reported on 28.03.90 in Blackwater Creek, a tributary of the Otumahana estuary (Fig. 13). Three small patches of eggs were found at this location, two of which were upstream of a culvert/floodgate and the other below. This is the first known record of spawning above a flood gate. Spawning also was observed for two hours the following day (29.03.90) at Granite Creek, another Otumahana estuary tributary. Additional spawning also was seen above the confluence with the Kongahu drain. Overall, spawning appeared to be more protracted and diffuse than the spawning reported from Baker Creek the previous year.

3.1.9 Buller River Catchment

The Buller River is one of New Zealand's largest rivers, with a catchment area of 6500 km^2. The headwaters drain the western faces of the St Arnaud and Spencer mountains which feed Lakes Rotoiti and Rotoroa. As it flows 150 km towards the sea, the Buller is supplemented by flows from the Matakitaki, Maruia, and Inangahua Rivers.

Bradshaws Creek drains isolated areas of pakahi west of the Buller River, discharging into the mainstem 2 km from the sea. A good deal of native riparian vegetation has been preserved along its slow-flowing, 20 km course.

3.1.9.1 Results from an unnamed tidal creek

Spawning was observed in a small tidal creek entering the eastern side of Buller Harbour on 10.02.89 (Fig. 14). Small shoals of mature inanga were seen along the stream margins 1.5 h before high tide, but, by the time of high water, the shoals had increased in numbers to over 1000 individuals. Spawning began 45 minutes after high tide, and was limited to two small sites less than 1 m^2 in area. These sites comprised a gently inclined grassed section of the true left bank, between the creek and the yacht sheds, and around the base of a large flax on the opposite bank. After 25 minutes, spawning had abated and had ceased five minutes later.

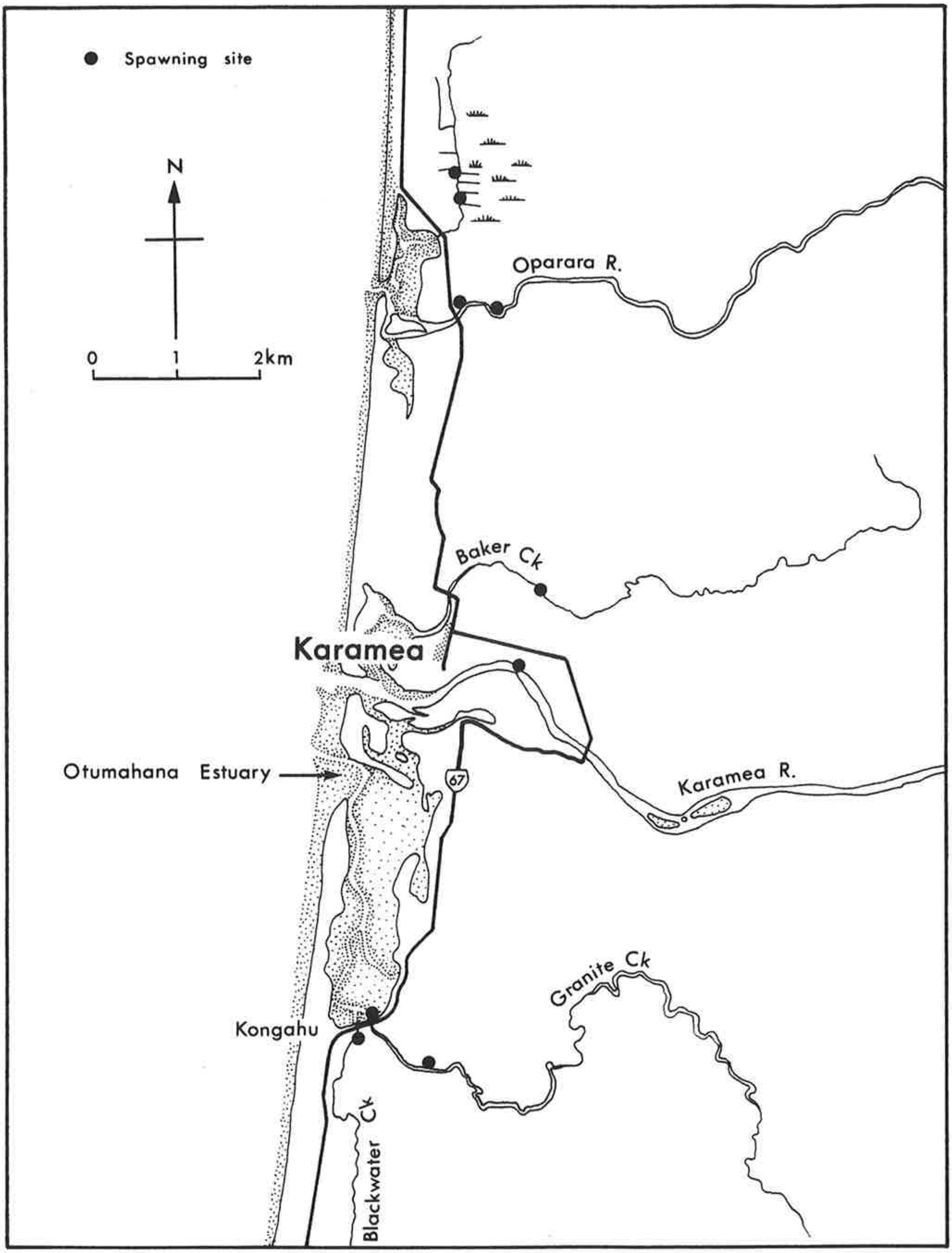

FIGURE 13. Inanga spawning sites in the Karamea and Oparara catchments.

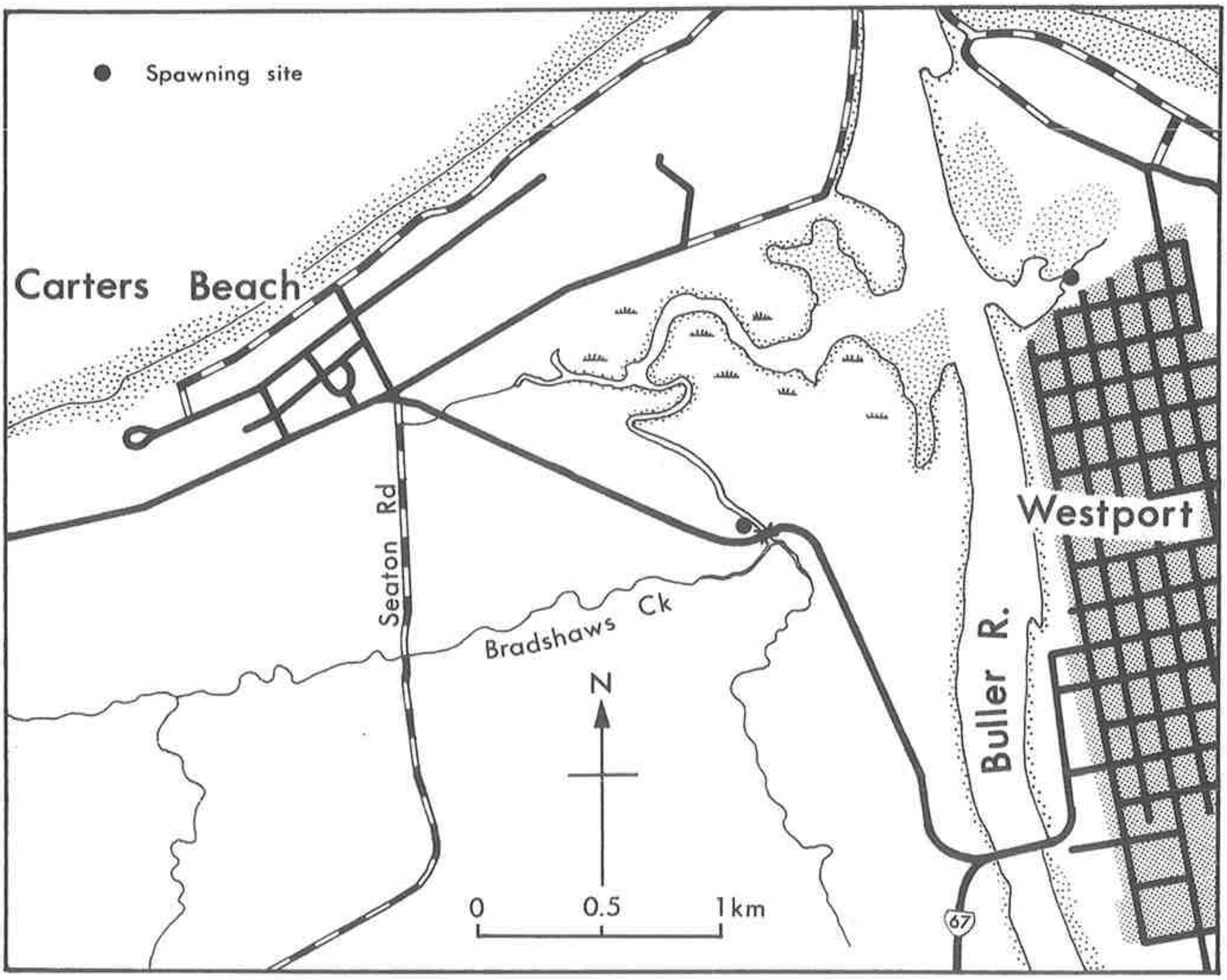

FIGURE 14. Inanga spawning sites in the lower reaches of the Buller River.

3.1.9.2 Results from Bradshaws Creek

Seven shoals of inanga were seen in Bradshaws Creek during the February spring tides in 1989, but no spawning sites were found during the February or March surveys that year. However, the surveys may have been too early in the season, as a landowner reported large shoals of inanga migrating upstream on 07.05.89.

Further investigations were carried out in Bradshaws Creek during the 1990 season, upstream of the area surveyed in 1989. Eyewitness accounts of substantial downstream movement of fish towards the estuary during February and March strongly suggested that spawning was taking place somewhere in the lower reaches. On 28.03.90, small shoals (comprising about 40 inanga) were seen swimming upstream on the rising tide from the estuarine area to the vicinity of the Westport/Carters Road bridge. The following day, similar behaviour was recorded, but the shoals became much larger, involving as many as 500 fish, and schooled amongst the flooded bank vegetation for a period of time. Upon capture, these fish proved to be ripe. After the tide had peaked, the fish dispersed quickly, and no spawning appeared to have taken place. On 30.03.90, spawning took place in the locality where inanga had schooled on the previous two days. The spawning zone extended from the true left bank of the Westport/Carters Road bridge to 200 m downstream. Spawning commenced about an hour after high tide and continued for about 35 minutes. After spawning had ceased, spent fish swam upstream in a very large shoal, reportedly of such length that it took 45 minutes for the shoal to pass a fixed reference point. Vegetation at the spawning site consisted of ungrazed, tall, *Festuca* grass.

3.1.10 Grey River Catchment

The Grey River arises in the Southern Alps and has a total catchment area of 3830 km^2. The main river follows a braided course, except for the last 16 km, where it flows in a single confined channel. The river bed is dredged from Greymouth to the sea, to facilitate ship passage.

Cobden Island is a section of river flat on the true right bank which has been largely occluded from the surrounding land by the Grey River mainstem (Fig. 15). The island is drained by two small channels. It is about 0.3 km^2 in area, and is used as a site for dumping landfill, as well as being adjacent to the Greymouth rubbish dump.

On the spring tides from 28.02.90 - 02.03.90, inanga were observed spawning in a channel flowing from the swampy, low-lying Cobden Island (Fig. 15). Prior to spawning and to the tide peaking, large numbers of inanga and a cloud of milt were seen at the mouth of a channel draining Cobden Island. Spawning commenced in the Cobden Island tributary 30 minutes after high tide, and ceased 30 minutes later, in water which was almost completely fresh (3% salt). Three spawning sites were identified, and several ripe fish were found stranded amongst the basal roots of grasses. At the northern spawning site, eggs were deposited amongst a grass community dominated by jointed rush and tall fescue, although creeping jenny and horsebane also were common. Eggs at the southern site were distributed amongst largely native vegetation, oioi (jointed wire rush), flax, and toetoe (Appendix VIII).

A separate channel closer to the sea also was surveyed on 28.02.90 and 01.03.90. However, no spawning activity was found, despite suitable vegetation. This habitat was badly polluted owing to run off from domestic waste, although shoals of ripe fish were reported in the area. Unfortunately, at the time of writing, the recorded spawning sites on Cobden Island were threatened by encroaching landfill.

3.1.11 Taramakau River Catchment

The Taramakau River has a catchment area of approximately 960 km^2, and rises from the western side of the Southern Alps. The river follows a wide braided course for much of its 80 km length. A small area of coastal scrub and swampland south of the mainstem,

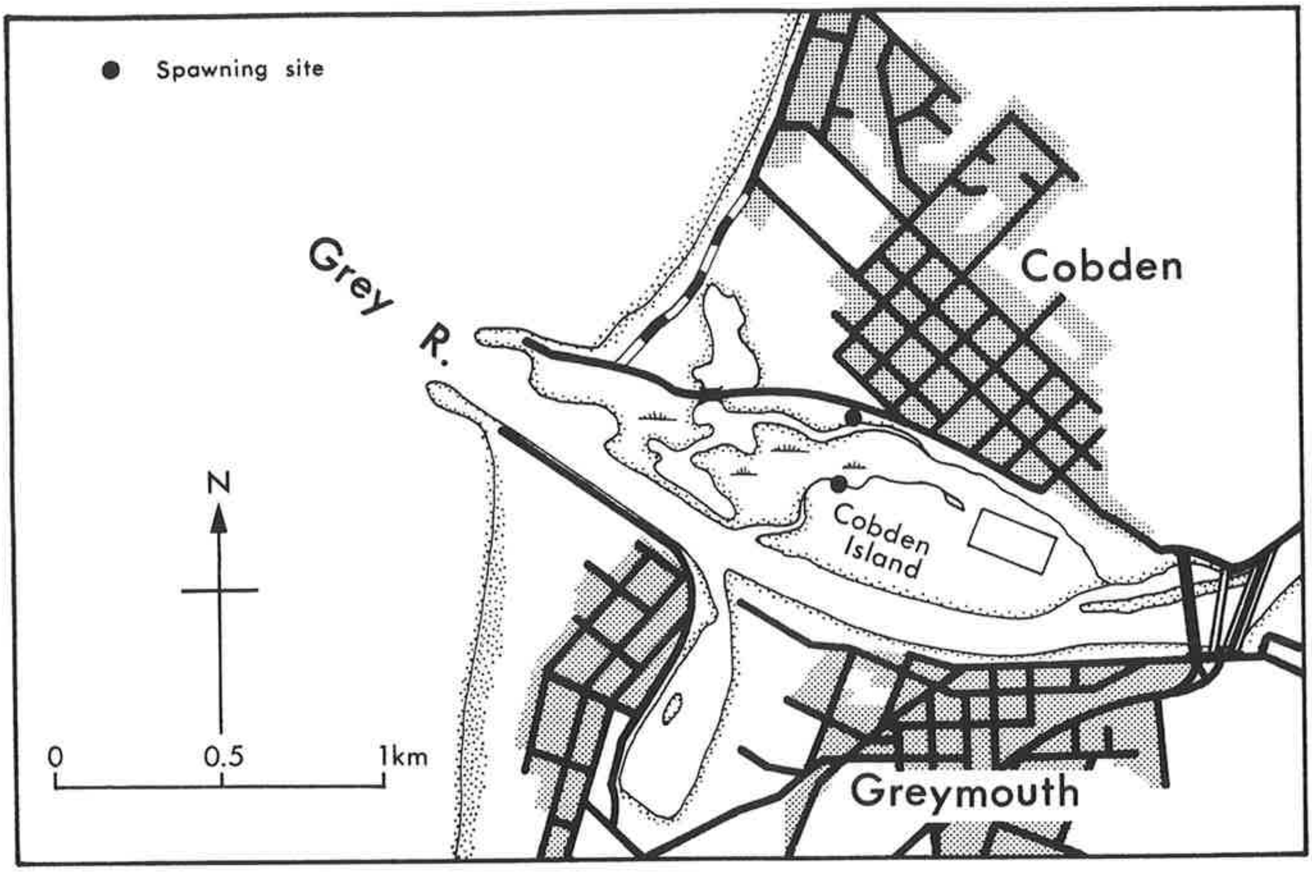

FIGURE 15. The two major inanga spawning sites on Cobden Island, Grey River catchment.

west of Kumara Junction, is drained by Carson Creek and other small feeder streams (Fig. 16).

Spawning was discovered on 30.04.88, in an unnamed tributary of the Taramakau River (Fig. 16). Long pasture grass (*Festuca* sp.) was associated with inanga spawning, but small numbers of eggs also were found on flax and sedge. This area was subject to grazing by horses at the time of the survey.

3.1.12 Hokitika River Catchment

With a catchment area of 1100 km^2, this large river receives a number of tributaries draining the main divide. The major tributaries merge on a floodplain west of Lake Kaniere, before flowing 15 km along a braided channel to the sea. Mean annual flow is 30 m^3/s, measured at Collier Creek, 24 km from the mouth.

Mahinapua Creek, the outlet for Lake Mahinapua, runs parallel to the coast for 7.5 km before discharging into the Hokitika River, a few hundred metres above the mouth (Fig. 17). Vegetation in the lower reaches consists of exotic species (*Festuca* grass and gorse), and native vegetation (flax, oioi (jointed wire rush), and other native rushes (*Juncus* spp.)).

Between 18-21.03.88, and 16-21.04.88, shoals of ripe inanga were observed swimming downstream, below Mahinapua Creek road bridge. On 19 March and 18 April, ripe inanga were seen "reconnoitring" likely spawning sites on the ebb tide. About 30 minutes later, mixed schools of spent and slightly unripe fish were observed swimming back upstream under the road bridge. Therefore, although no actual spawning was observed or eggs found, spawning must have occurred somewhere downstream of the observation point.

Subsequently (on 29.04.88), inanga eggs were found on levee areas bordering the lower reaches of Mahinapua Creek downstream of the boatshed (Mitchell 1988). Below this location, the elevated, dryer conditions favoured growth of tall fescue, and some oioi, whereas jointed rush and spike sedge dominated the surrounding, low lying, wetter areas where eggs were not found. (The vegetation profile for this site is given in Appendix IXa.) Inanga eggs also were discovered along a major tributary, Fishermans Creek (Fig. 17), about 10 m from the normal water's edge, again on elevated land where the *Leptocarpus* vegetation was succeeded by *Festuca*, gorse, flax, and *Juncus* spp. This spawning zone did not extend more than 50 m from the confluence of the tributary and the mainstem. From 400 m above the saltwater wedge on Mahinapua Creek, working downstream on the true left bank, small numbers of

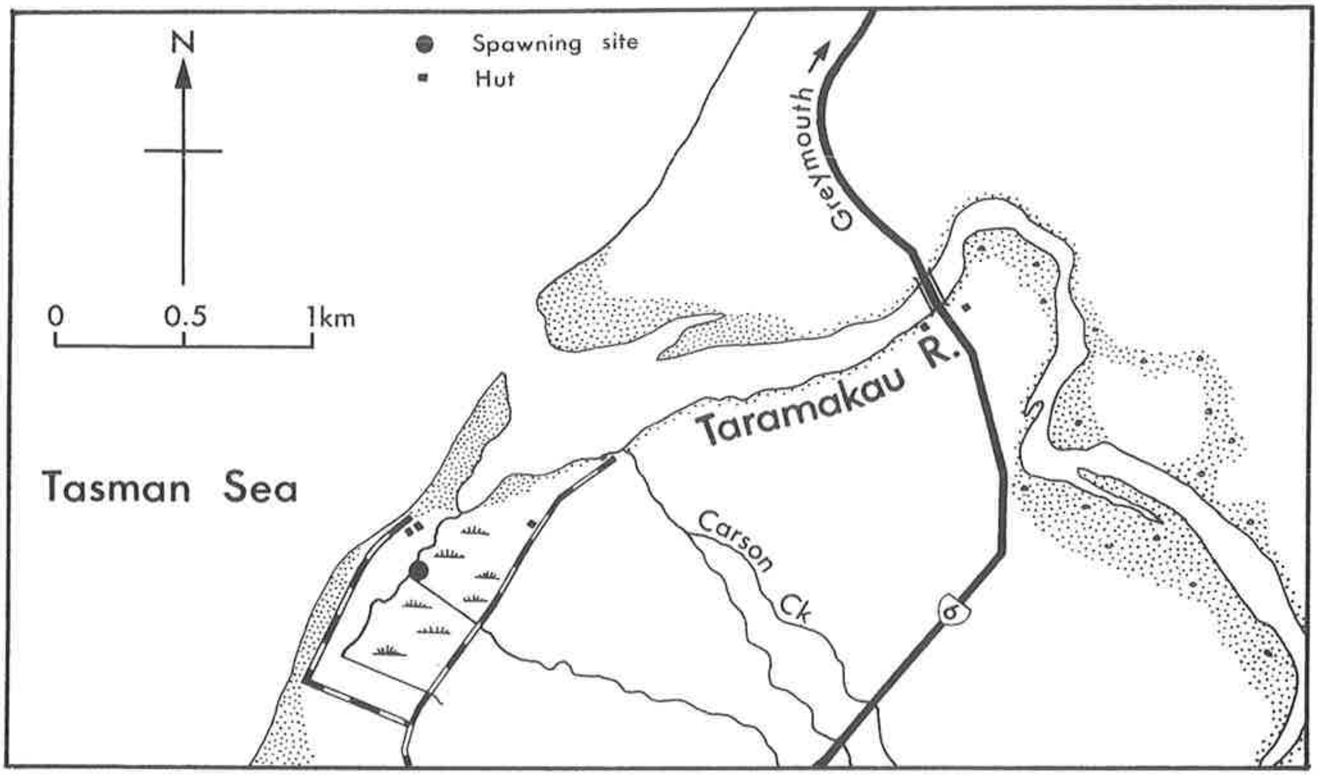

FIGURE 16. Inanga spawning site on the Taramakau River.

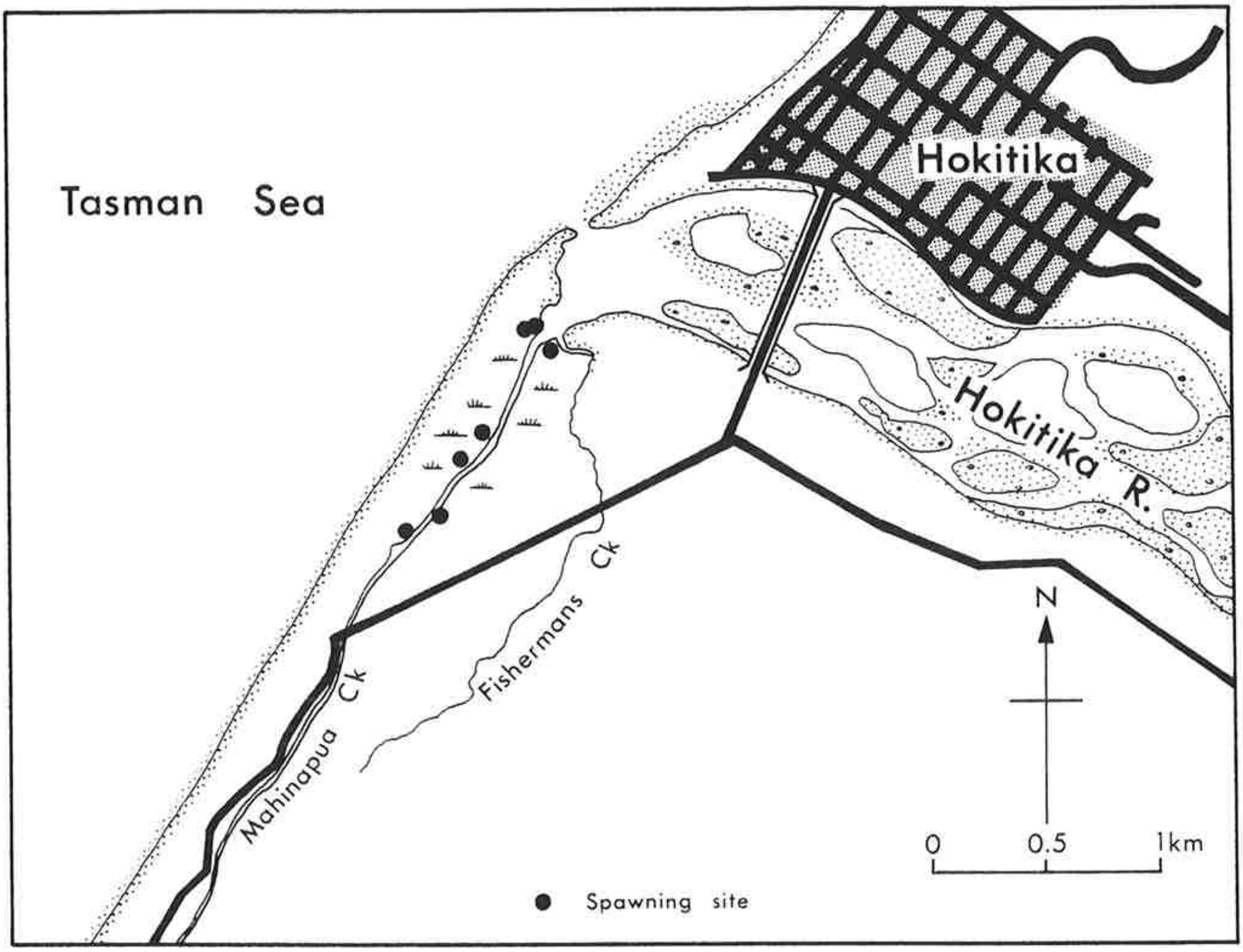

FIGURE 17. Inanga spawning sites on the Hokitika River.

eggs were found where the banks had been cleared of flax, and grasses and herbs dominated. This vegetation was identified as swamp millet, lotus, yorkshire fog, creeping bent, *Centella*, and buttercup. Still further downstream on the true left (west) bank, eggs again were associated with slightly higher areas, vegetated mainly with *Festuca*, *Carex* sp., an unidentified fine blue grass, wiwi (New Zealand rush), and spike rush. Eggs were hard to detect from this catchment, as they were covered in a thin layer of silt, which could explain why they escaped detection earlier in the spawning season. A total of eight spawning sites was located along Mahinapua Creek.

3.1.13 Waitaha River Catchment

The Waitaha River drains the western aspect of the Southern Alps, and has an approximate catchment area of 325 km^2. Although confined for much of its length by gorges, the river eventually flows across a wide valley floor. The Kakapotahi River (Little Waitaha) drains native forest on the Rangitoto Range, and augments the Waitaha mainstem 4 km from the mouth. In the lower reaches, within 0.5 km of the mouth, a tannin-stained stream drains an area of pakihi on the true right bank, north of the Waitaha River (Fig. 18). Riparian vegetation consisted of pasture grass, of variable thickness, growing through sandy banks.

A tributary on the true left of the mainstem flows from Ounatai lagoon, which receives runoff from wetlands in the Ianthe State Forest (Fig. 18). Thick riparian pasture grass, *Carex*, and flax lined the tidal reaches. Particularly in this locality, but also in places along the unnamed stream on the opposite bank, gorse thickets prevented widespread stock access and subsequent damage to riparian vegetation. Ounatai lagoon also drains into Te Rahotaiepa lagoon, south of the Waitaha catchment, and therefore has two mouths to the sea.

On 08-09.02.89, 2-3 days after the new moon, DOC and FFC staff surveyed the lower tidal reaches of the Waitaha River, and examined the stream draining wetlands to the north of the river, and the creek draining Ounatai lagoon.

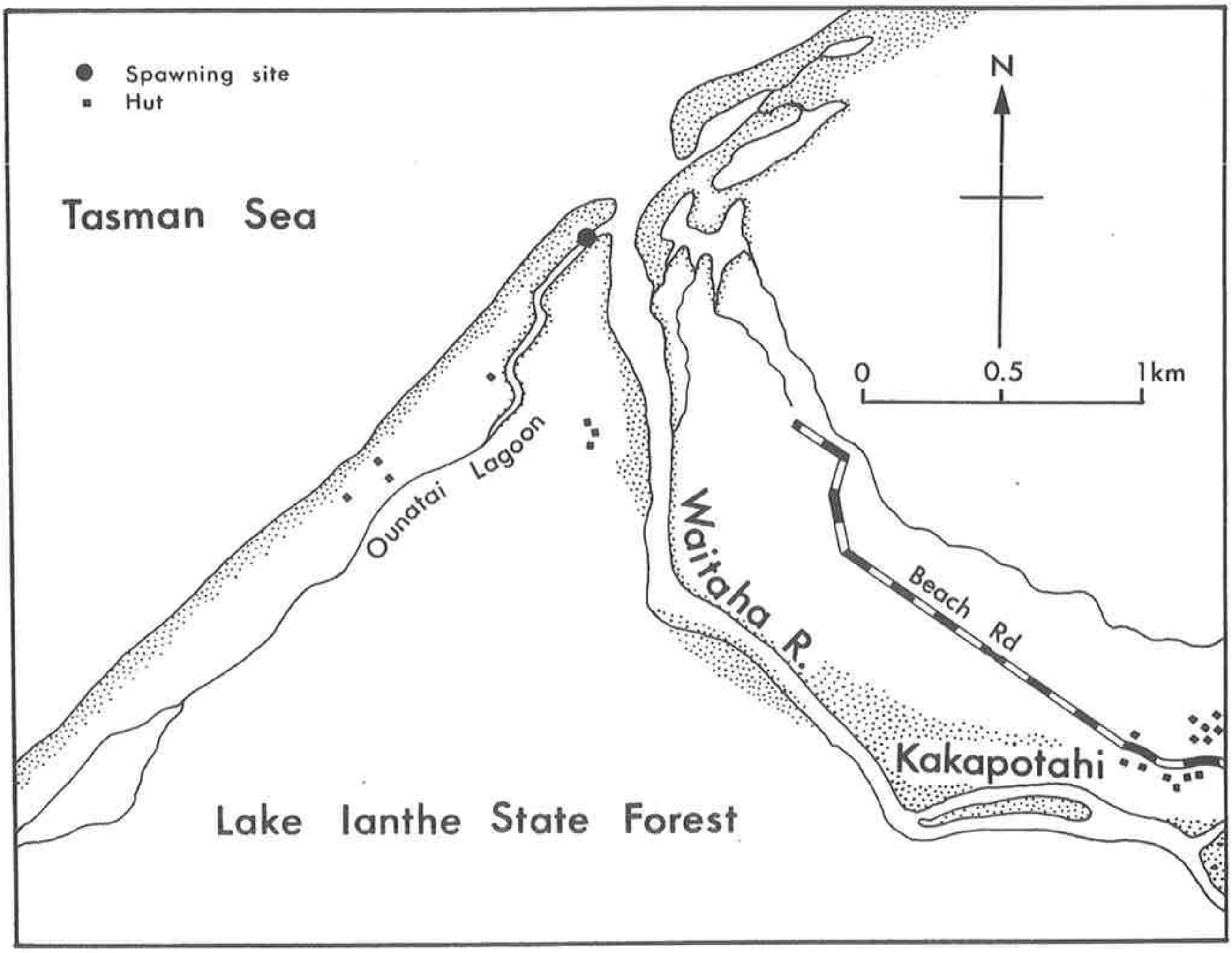

FIGURE 18. Inanga spawning site on the Waitaha River.

No spawning behaviour, or eggs, were observed in the northern tributary, despite the apparently suitable habitat in a limited area. The stream banks usually comprised little topsoil or humus at this site, and consisted largely of sand, with a thin cover of grass. However, there were some areas where the pasture grass was of sufficient length and thickness to offer suitable spawning habitat. Shoals of juvenile fish were observed, but relatively few adults were seen.

In the creek draining Ounatai lagoon, the saltwater wedge was monitored on the incoming tide to a distance 3 km upstream from the lagoon mouth. At the termination of the wedge, the riparian vegetation comprised dense podocarp forest, with ferns and flaxes lining steep-sided banks. The steep nature of the banks, and the unsuitable vegetation, suggested that sites further downstream would be more suitable for spawning. A second boundary of saline and fresh water had formed about 0.5 km from the confluence of Ounatai lagoon and the Waitaha mainstem, probably because of the two mouths. At 15 minutes after high tide, spawning was observed about 40 m downstream of the second saltwater wedge on the true right bank, with ripe inanga swimming through emergent rushes to spawn in the softer grasses lining the banks. Spawning persisted for approximately 45 minutes. On the true left bank, spawning extended over 6 m of *Carex* and *Lotus* for about the same period. Spawning ceased one hour after high tide, when the ebb tide surface velocity was about 0.2 m/s.

3.1.14 Wanganui River Catchment

The Wanganui River flows for about 50 km, draining a catchment area of over 500 km^2. The river rises from glaciers in the Southern Alps, and derives much of its flow from the Wilberg and Smyth Ranges. Below State Highway (S.H.) 6, the river flows out of the confines of the bush-clad valley onto a wide floodplain, and follows a braided course for 30 km before discharging into the Tasman Sea. Vegetation in the lower reaches of the mainstem consisted of native scrub with small patches of grass on the south bank, whereas the north bank was composed mainly of grasses growing through sand.

The Oneone River enters the Wanganui River lagoon after draining scrub and remnant bush on the south bank for 5 km (Fig. 19). Vegetation in the lower 200 m of this tributary consisted of a mixture of grasses, flax, and toetoe. On 10.03.89, the lower 200 m of the Oneone River was searched for inanga spawning and eggs. No eggs or inanga were observed, although the vegetation appeared suitable. Spawning was observed downstream of the coastal track footbridge (Fig. 19) in February 1990 by DOC field staff, and overall eight spawning sites have been discovered from this catchment. Salinity readings indicated that the spring tide saltwater wedge penetrated upstream at least as far as the footbridge. Eggs were found around the bases of toetoe with an undergrowth of tall fescue, spike rush, and *Lotus*. Eight spawning zones within a 20 m radius were found at this location, and the vegetation profile is shown in Appendix IXb.

3.1.15 Poerua River Catchment

The Poerua is a small river, with a catchment area of 225 km^2, and a length of about 40 km. Rising from Mt Kensington, the river flows down a steep, bush-clad valley, receiving water from both the Wilberg and Adams Ranges, before the valley opens out 6 km above S.H.6. At this point, the river begins to braid over a broad floodplain (Fig. 19). Relative to its size, the Poerua River has substantial river flats, which have been cleared, draglined, and pastoralised. A major lowland tributary, the Hinatua River, drains a substantial swampy area to the south of the mainstem, before entering the Hikimutu (Poerua) lagoon.

On 28.02.90, three days after the new moon, inanga were observed spawning on punga stumps, and amongst a large section of *Festuca*, that had fallen from the eroded true right bank of the Poerua mainstem, less than 1 km from the sea. The saltwater wedge was approximately 50 m below the site. At the time, very little other suitable vegetation was available for

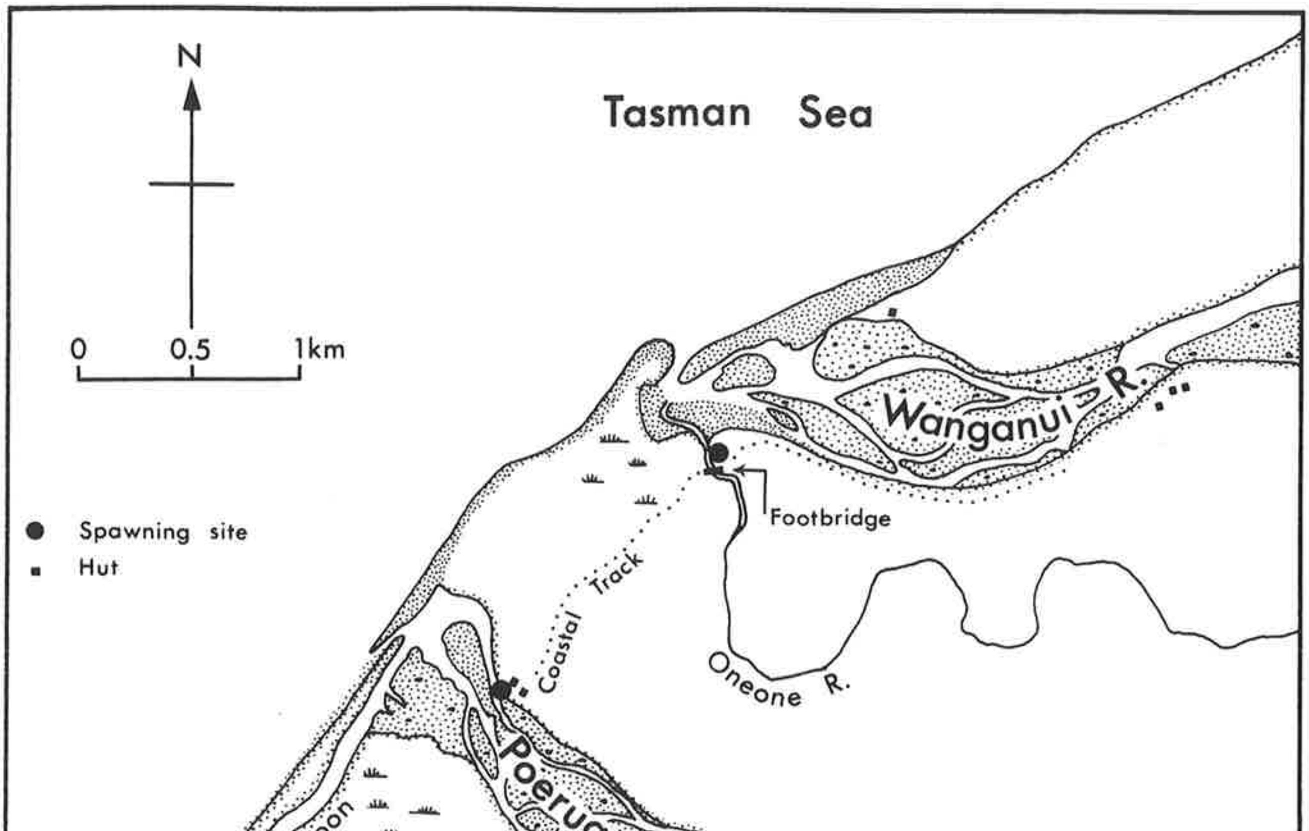

FIGURE 19. Inanga spawning sites on the Wanganui and Poerua Rivers.

spawning to take place, and fish were observed to beach themselves onto the river gravels, apparently in an attempt to reach grasses just clear of the water. Erosion over the last few years has stripped this location of grasses and flax.

3.1.16 Waitangitaona River Catchment

The Waitangitaona River rises from the Price Range, but also receives ice melt from glaciers in the Tatere Range, east of Franz Joseph township. After flowing for approximately 13 km, the Waitangitaona follows a slightly braided course across the same broad, pastoralised valley as the Whataroa River. However, in the last 10 km before entering the sea 2 km north of Okarito lagoon, the Waitangitaona River meanders through low-lying scrubland and remnant bush.

Approximately 1 km from the mouth, a narrow, weed-choked stream enters the mainstem on the true left bank, in the vicinity of the DOC hut (NZMS1 S63 889040) (Fig. 20). Riparian vegetation at this site comprised *Carex* and *Lotus*, similar to vegetation in Ounatai lagoon. Most of the northern bank of the mainstem consisted of similar vegetation, which was thick in places.

During the field survey on 10.02.89, the lower reaches of the Waitangitaona River were surveyed by FFC and DOC staff. A shoal of approximately 30 adult inanga was observed swimming in the narrow creek which runs beside the DOC hut, about two hours before high tide. These fish were not feeding, and stayed tightly grouped, swimming parallel and adjacent to the banks. Approximately 27 minutes after high tide, inanga began spawning at two locations: just upstream of a vehicle ford, in a luxuriant patch of *Carex* and *Lotus* on the true right bank, and right at the confluence of the creek and the mainstem, where the vegetation comprised mainly pasture grasses. Spawning had largely finished after 30 minutes, but there was still some minor activity 87 minutes after high tide when staff left the site. This creek was approximately 400 m above the saltwater wedge on the mainstem. Thus, although tidal, the creek water was entirely fresh throughout spawning. Limited spawning also took place on the spring tide on a small island in the mainstem, at, or just below, the upstream limit of the saltwater wedge. Here, spawning was limited to a 1 m patch of *Carex*, and commenced about 30 minutes after high tide.

This area was revisited in 1990, and inanga spawning again took place in the tributary flowing past the DOC

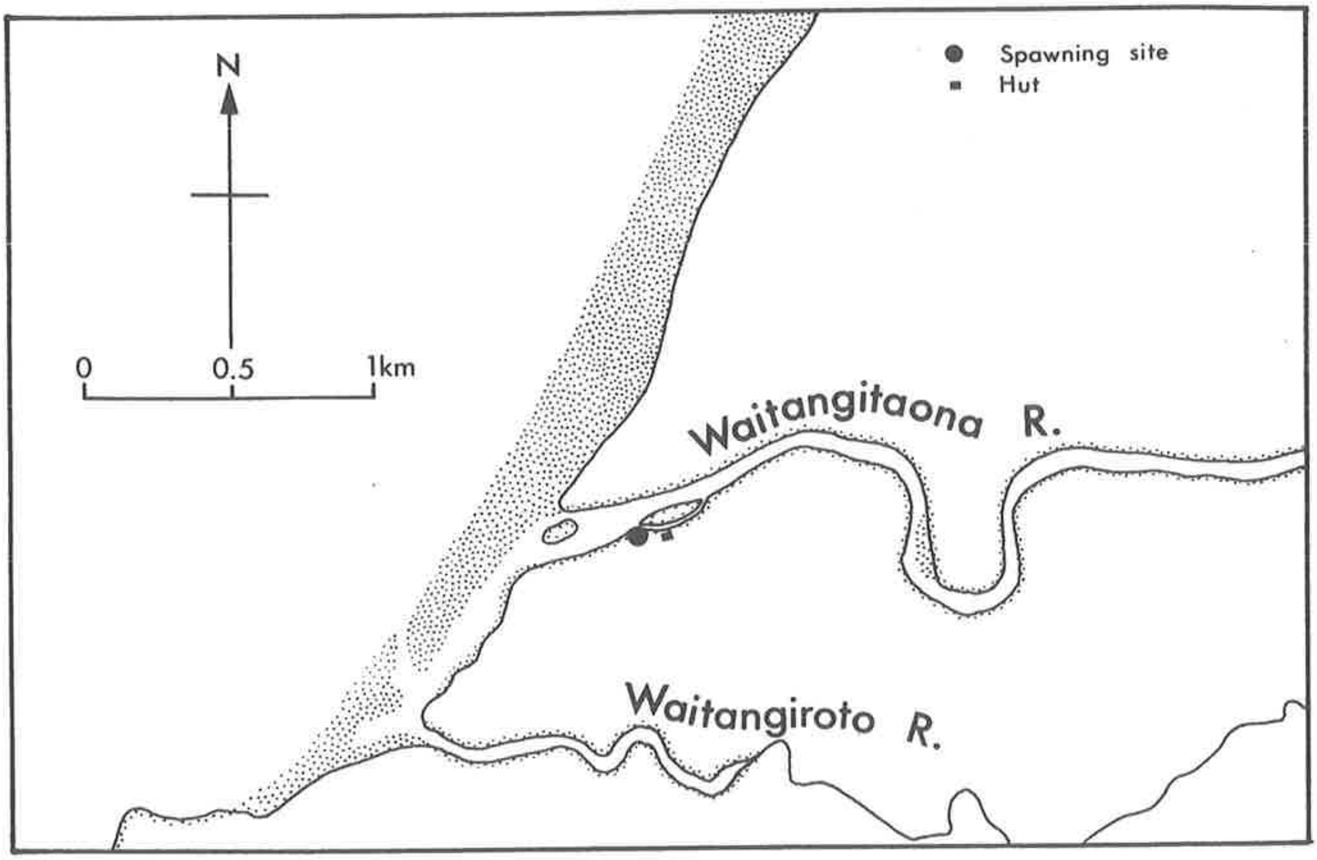

FIGURE 20. Inanga spawning site on a tributary of the Waitangitaona River.

hut. However, eggs were not deposited at exactly the same locations as the previous year. Vegetation profiles were carried out at the two sites where spawning took place (Appendix X), and tussock sedge, yorkshire fog, *Lotus*, and creeping bent predominated. Extensive grazing had occurred since the previous year, and it appeared that clover had been grazed selectively. Salinity measurements indicated that the saltwater wedge penetrated further up the mainstem than it had in 1989, although, like the previous season, spawning in this tributary was entirely in fresh water.

3.1.17 Manakaiaua River Catchment

The Manakaiaua is a small river, with a catchment area of about 60 km^2, which rises from Mt Ritchie, in the Bare Rocky Range at an altitude of 1230 m. For most of its 16 km length, the river flows through a narrow, glacially-shaped, bush-clad valley, before entering a wetland only 5 km from the river mouth. Sam Creek is one of six small, wetland-derived streams which enter the tannin-stained mainstem within 2 km of the mouth (Fig. 21). It is 500 m long, 2 m wide, and enters the Manakaiaua River 800 m from the mouth. The riparian borders of this small creek are clad with flaxes, rushes, and exotic grasses and herbs.

Large shoals and intensive inanga spawning were recorded in Sam Creek by DOC staff on 28.03.90. Inanga eggs were scattered amongst leaf litter around the base of flaxes, tussock sedge, and *Lotus*. (Vegetation profiles for two spawning sites from this location are shown in Appendix XI.) Further spawning took place on 27.04.90, and many stranded and spent inanga were taken from the spawning site.

3.1.18 Makawhio (Jacobs) River Catchment

Rising from the Bare Rocky and Bannock Rae Ranges, and fed by rain and snow melt, the Makawhio has a catchment area of approximately 175 km^2 and a length of 31 km. The river is initially clear with a slight blue tinge, and flows swiftly over a boulder bed in the upper reaches. However, after flowing for 21 km in a relatively wide valley, the valley floor forms a broad floodplain, and the river begins to braid slightly. For the last 10 km, the Makawhio drains pasture and a large area of pakahi to the south (Fig. 21). The tributary which drains the pakahi is Papakeri Creek. In the past, the river also received flow from Lake Kini, but this has since been directly draglined to the sea.

Three spawning sites were found in this catchment between 26-28.03.90. These were Papakeri Creek, a mainstem backwater, and a creek entering the mainstem on the true right (north) bank (Fig. 21). Spawning in Papakeri Creek was restricted to a small depression in the main channel, occupied only 1 m^2, and began minutes after the turn of the tide. Spawning in the mainstem backwater occupied 2 m^2 of turf, dominated by creeping bent, Yorkshire fog, and *Lotus* (Appendix XIIa). However, the spawning site on the north bank creek (Fig. 22) was of substantial size, attracting shoals of more than 300 inanga. Eggs from this large site were associated with exotic plant species - chewings fescue (70%), with some *Lotus* (15%) and creeping bent (5%) (Appendix XIIb). Both the mainstem backwater and north bank spawning sites were about 70 m upstream of the saltwater wedge, whereas the Papakeri Creek site was just below the saltwater wedge.

3.1.19 Waita River Catchment

The rain-fed Waita River rises from the Mataketake Range at an elevation of about 1220 m and flows for about 18 km. The catchment of about 152 km^2 comprises the western face of the Mataketake Range, and the south-western faces of Law and Arnott Hills. At about 50 m elevation, the river flows out of a narrow, steep-sided valley and becomes broad and shallow, with extensive riffle areas. A wide flood bed develops, with pastured sections grazed by cattle. Braiding is common in the 5 km of the mainstem above the confluence with the Maori River. Maori River, the principal tributary of the Waita, drains an extensive pakihi area of about 3000 hectares, including shallow dune lakes. The Waita has a long (1 km), thin lagoon which runs parallel to the coast before discharging into the sea at its southern end.

At the time of our survey (08.03.90), the Waita River had a long, narrow lagoon, the seaward bank consisting of shingle, and the coastal bank vegetated in fine grasses and flax. On the spring tide, two small shoals of adult inanga were observed swimming at the top of the lagoon. However, despite searching for eggs in apparently suitable vegetation, no eggs were found. Salinity readings indicated that there was only a trace of salt in the lagoon, as the waters of the Waita ran down a long rapid into the sea, probably denying appreciable seawater egress into the river on the high tides.

3.1.20 Turnbull River Catchment

The Turnbull rises from the western face of the Browning Range and MacPherson Heights, within Mount Aspiring National Park. Receiving water from the Selbourne Range, and confined by steep valley walls

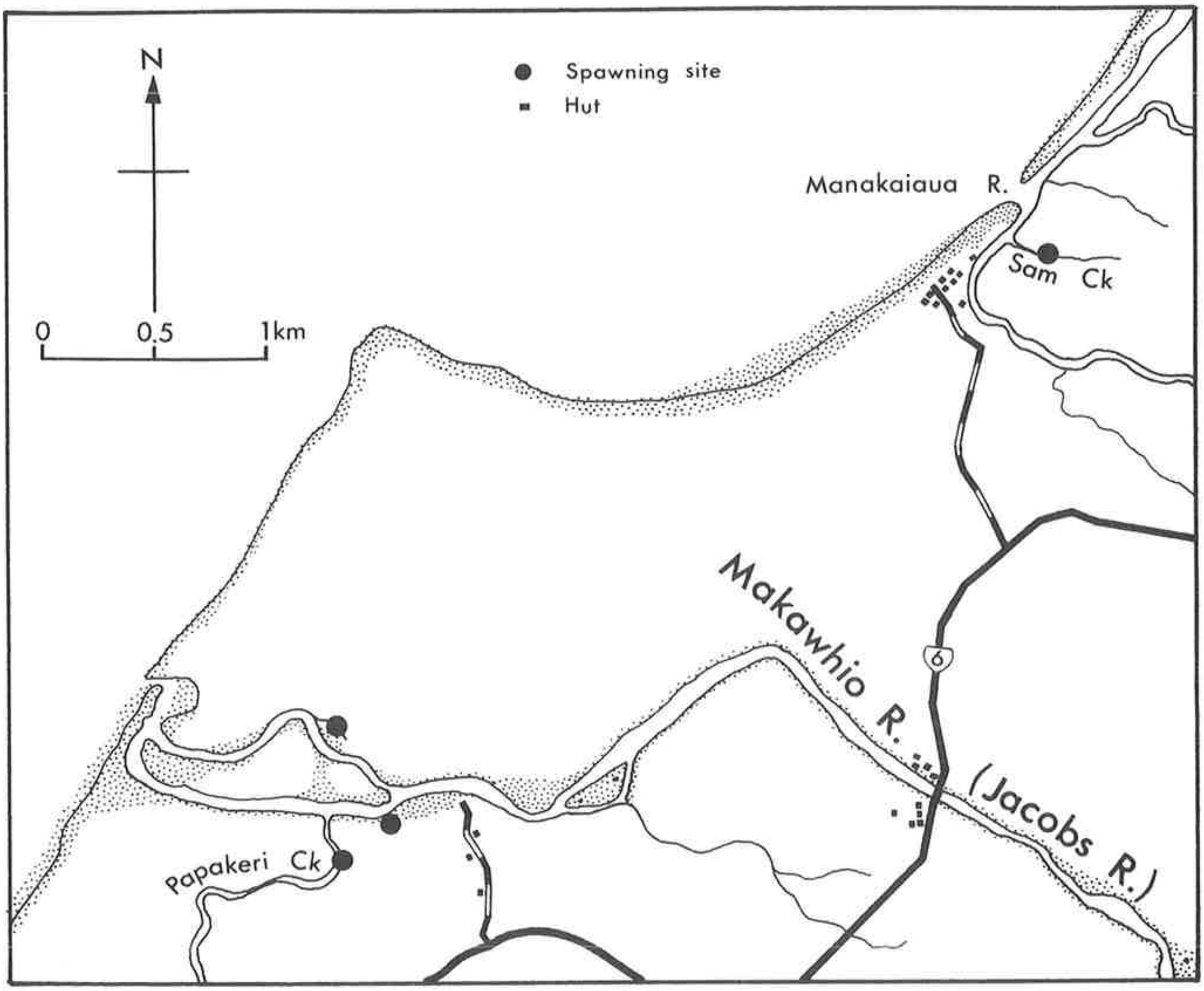

FIGURE 21. Inanga spawning sites in the Manakaiaua and Makawhio (Jacobs) River catchments.

and gorges for 16 km, the Turnbull meanders north-east for a further 10 km over a shingle bed before entering a common lagoon with the Okuru and Hapuka Rivers.

Collyer Creek enters the Turnbull mainstem 2 km from the sea. This heavily tannin-stained creek drains pakahi and kahikatea forest over its 7 km length, and its stream margins are similarly dominated by native vegetation. Flaxes, hebes, and mikimiki are predominant in the riparian flora, although exotic herbs and grasses grow amongst the taller native species.

Salinity measurements along Collyer Creek showed that the spring tide saltwater wedge extended 1.2 km upstream of the confluence. On 10.03.89, two days after the new moon, spawning commenced at four sites. The most upstream site (site 1, Fig. 23) and the most downstream site (site 4) were approximately 110 m and 400 m, respectively, below the saltwater wedge. Spawning commenced at high tide and ceased 30 minutes later. At its peak, spawning was very active with large milt clouds produced, particularly at site 3 (Fig. 24). This was the largest site, and was about 310 m below the saltwater wedge. It was the site with the highest density of eggs recorded from any South Island spawning survey. Kelly (1989) reported "Eggs at site 3 were spread over an area of about 2 m in a mat up to 5 cm deep". Riparian vegetation was dominated by native shrubs, grasses, and rushes (Appendix XIIIa). Mikimiki constituted 45% of the spawning area, flax 40%, with tussock sedge and koromiko each forming 15%. Tall fescue (10%), *Lotus* (2%), and creeping buttercup (2%) comprised a relatively low representation of exotic plants, compared to more modified spawning sites.

The vegetation profile for site 4 is shown in Appendix XIIIb. In contrast to site 3, site 4 was dominated by

FIGURE 22. Evaluating an inanga spawning site on the Makawhio River. Left to right: Colin Meurk (DSIR), Herb Lochford (landowner), Stephen O'Dey (DOC), and Greg Kelly (FFC). (Photo: A. Buckland.)

exotic grasses, apart from two large flaxes that bordered the spawning area. Tall fescue, yorkshire fog, creeping bent, and a small amount of *Lotus* formed a thick, moist bed of vegetation from which a high density of eggs was recorded. Examination of the spawning zones at low tide showed that eggs were amongst fine grass and the root hairs of large flax bushes, 3-4 m from the bank edge. Collectively, the spawning ground was about 4 m^2 in area.

The following day (11.03.89), four new sites were discovered downstream of those found previously (sites 5-8, Fig. 23). Salinity readings indicated that the tidal amplitude was lower (by 0.2 m) than the previous day, and the salt wedge did not intrude so far upstream. Spawning commenced 15 minutes after high tide, firstly at the upstream sites identified the day before; initially at sites 2 and 3, but after another 15 minutes, spawning began at site 4, a small island in the mainstem of Collyer Creek. It is not known when spawning began at the four lower sites, but spawning activity was relatively minor compared to that recorded on the previous day. All spawning activity had ceased after about 50 minutes. The vegetation at spawning sites 5 and 6 comprised koromiko and mikimiki bushes, whereas sites 7 and 8 were amongst pasture grasses.

3.1.21 Waihopai River Catchment

The Waihopai River drains pasture and wetlands to the north and east of Invercargill, through an extensive system of drains and flow regulators. In the lowest reaches, where the Waihopai flows past Invercargill, the river is stopbanked. At the time of writing (October 1991), a flood protection scheme was proposed, involving realignment of the river, renewal of stopbanks, and construction of a detention dam.

Owing to climatic conditions, and the lateness of the spawning survey (May 1988), no spawning or eggs were observed. However, it was considered that the area of rushes in the lower reaches was probably not used for spawning, although there appeared to be potential spawning sites in the vicinity of the Railway and North Road bridges. Sites upstream of this area also may be used (Eldon 1988a).

3.1.22 Titiroa River Catchment

The Titiroa River drains pasture land south of Wyndham, and, after being augmented by the Waimahaka Stream and flowing for 6 km, discharges into Toetoes Harbour, near the Mataura River mouth. The river supports a very popular whitebait fishery.

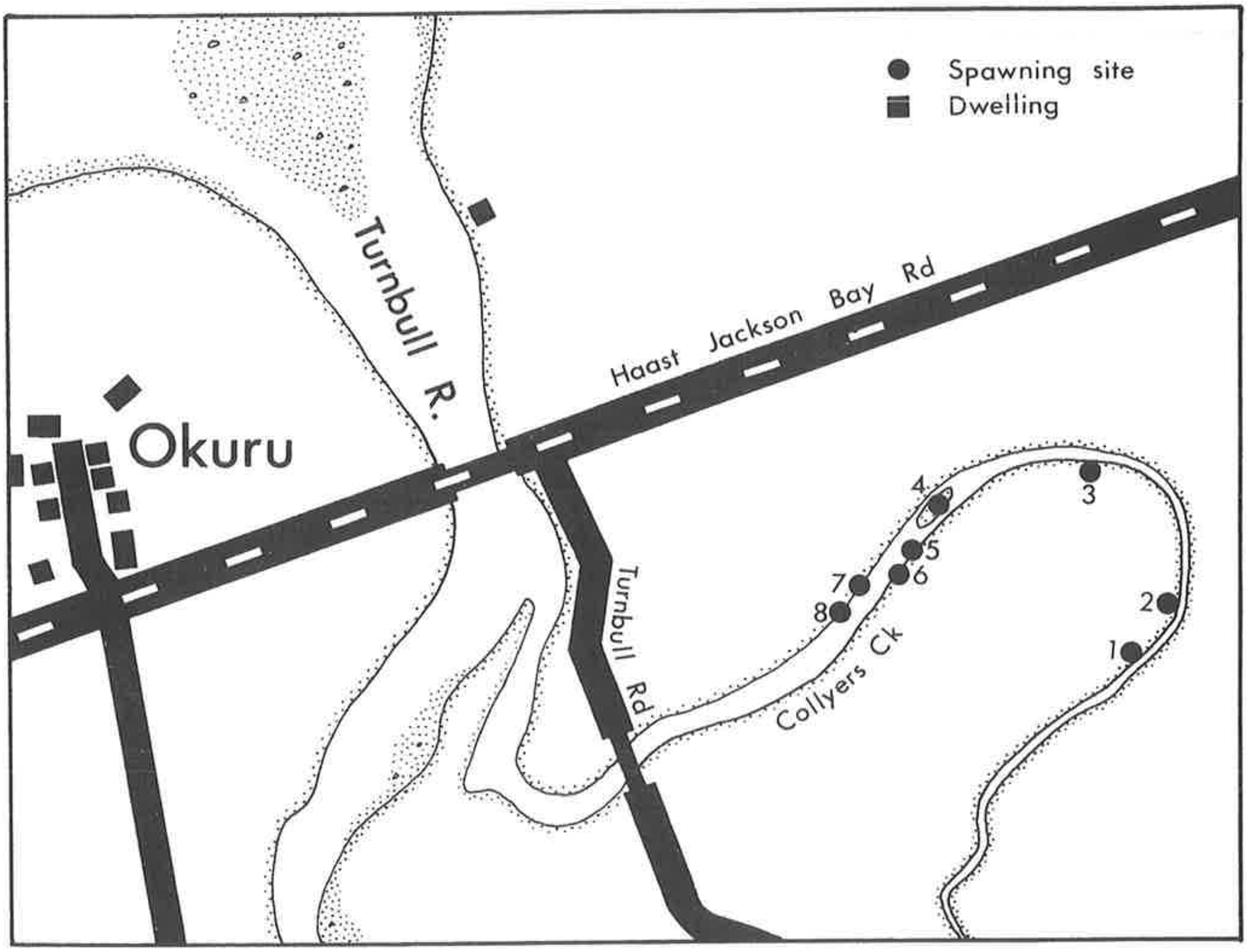

FIGURE 23. Inanga spawning sites on the Turnbull River.

As was the situation on the Waihopai River, the lateness of the season, poor weather, and flooding prevented any field observations of spawning, although the true right bank, from the tide gates to 1.5 km downstream, seemed to provide some suitable spawning habitat for inanga. In the vicinity of the tide gates, and along the true left bank, vegetation was considered too short or sparse to support whitebait spawning (Eldon 1988a).

3.2 Summary of Results

Results from the field studies indicate that inanga spawning normally occurs a few days after the new moon tide (mean = 2.5 days, sd = 1.6, n = 39), and always after the tide had turned, often when there was a definite ebb current (Appendix IV). There were only three spawning observations which did not follow a new moon. Quite active spawning was recorded from the Grey River on the day of the new moon, and occurred a day before the new moon on the Makawhio River, when a major fresh had raised river levels prematurely. Limited spawning also occurred in a side creek of the Kaiapoi River on the day of the new moon (Appendix IV). On average, spawning did not start until more than 30 minutes after the tide had peaked (mean = 42 minutes, sd = 25.6, n = 24), and finished more than an hour after high water (mean = 76.1 minutes, sd = 23.6, n = 20), although the period between high water and spawning commencing/finishing times varied between spawning sites. In particular, spawning on a Lake Ellesmere tributary was very protracted, and lasted 2 hours. If this atypical site is excluded, and using only data where both commencing and finishing times of spawning are available, then spawning took about half an hour (mean = 36.2 minutes, sd = 13.3, n = 17).

Most spawning sites were just above, or at, the limit of saltwater intrusion (Appendix IV), with only those on the Ashley, Saltwater, Kaiapoi, Waitaha, and Turnbull Rivers being recorded below the saltwater wedge.

FIGURE 24. Inanga spawning site (site 3) on Collyer Creek, Turnbull River catchment.

Unfortunately, few data were collected on how far upstream spawning sites were from the saltwater wedge, but the average distance on three south Westland rivers was 140 m (although spawning on the Waitangitaona River was 300 m upstream of the wedge). However, on the spring tides in April 1990, the saltwater wedge intruded to within 50 m of the Waitangitaona spawning sites. On the east coast, spawning took place 1500 m above the wedge in the Heathcote River, but an extended zone of brackish water may be pushed upstream in front of the wedge on the incoming tide (FFC unpublished data). The Avon River spawning site is known to be at the upstream limit of the estuarine water.

Of the seven sites where spawning took place downstream of the saltwater wedge, the mean distance was 140 m, although it was quite variable (sd = 212). If the atypical Avon and Heathcote data are excluded (these rivers feed a large estuary), most spawning sites were between 1.0 km and 3.5 km upstream from the sea.

There is some evidence (FFC unpublished data) that inanga utilise sites progressively further downstream on successive, falling, spring tides. This was the case on the Turnbull and Karamea Rivers, where observers recorded spawning grounds being utilised for two and four days in succession.

The most commonly encountered vegetation upon which inanga eggs were deposited was exotic grasses (tall fescue, creeping bent, and yorkshire fog), but only when they were of sufficient blade length and foliage density (Appendix III). On the east coast, these were the predominant spawning vegetation at all but one site. The exception was the Kaiapoi River, where eggs were deposited in a bed of moss. Subdominant vegetation upon which smaller numbers of eggs were laid included rushes, flax, musk, and raupo.

Exotic grasses also were common spawning substrates on the West Coast, but the proportion of native vegetation, particularly in south Westland, was higher than in Canterbury. Six of the 10 native vegetation spawning areas were in the Turnbull River catchment (Appendix III). Predominant native species were sedges, flaxes, and rushes. A balanced mixture of native and exotic vegetation was recorded from another 14 locations on the West Coast. Land use in the catchments above Westland spawning areas had a high component of native bush and swamp, 14 locations containing at least some native bush, and 16 locations comprising some swampland.

In contrast, only one east coast location was dominated by native vegetation, Waikewai Creek (Lake Ellesmere), where eggs were found amongst leaf litter in a raupo bed. Further, 10 of the 12 east coast locations were dominated by exotic vegetation, four of the sites being completely exotic. The spawning site on the Avon River (Avondale bridge) had a mixture of both native and exotic plants.

4. DISCUSSION

4.1 Physical Factors Affecting Spawning

4.1.1 Spawning Season

Whitebait spawning takes place mainly between the months of February to April, although small numbers of ripe inanga may be found throughout the year (McDowall 1968). This allows the whitebait to develop at sea over the winter, and, possibly, to maximise growth by exploiting the warm water and large numbers of freshwater invertebrates in the spring and summer.

In this survey, spawning was observed as late as May, and, on the Oparara River, as early as December. Spent inanga were captured while swimming upstream after spawning in Mahinapua Creek (Hokitika River) in April, and examined. Females had small, residual numbers of mature ova, but also ripening immature ovaries which were evidently going to develop in the current spawning season (Eldon 1988b). These fish also had been feeding (largely on inanga eggs), indicating that they may survive to spawn again in the same season, although inanga, once spent, are not known to survive the winter (McDowall 1990).

If inanga ovaries are regenerating in April, and the fish do not overwinter, then it implies that the fish must spawn again in May and June. So far, there are no records of inanga spawning this late, although the fact that small quantities of whitebait can be caught from most rivers all year round (McDowall 1969), suggests that limited spawning may take place at other times of the year. Conceivably, if inanga can spawn at least twice in a season, then it would provide a degree of resiliency to the fishery should a catastrophic event befall the first cohort.

4.1.2 Lunar Periodicity

Burnet (1965) reported that timing of the downstream migrations of ripe inanga was correlated to both lunar and tidal events. However, the mechanism by which the fish detect and co-ordinate spawning migrations from habitats upstream of the tidal influence remains a mystery. Other fish show lunar periodicity with respect to reproductive behaviour, but inanga is one of the very few species known to exhibit lunar periodic behaviour while many kilometres upstream of salt water (McDowall 1969).

During the three years of this study, it was noted that the tidal cycle on the east coast differed fundamentally from that on the west coast of the South Island. On the east coast, in the late summers of 1988 - 1990, full moon tides were often nonexistent, and therefore the period between high spring tides was about 28 days (Fig. 25). Further, east coast new moon tides were sustained (for as long as six days), well after the new moon. These intercoastal tidal differences are due to local geographical effects (Hydrographic Branch, Royal New Zealand Navy pers. comm.). In contrast, west coast spring tide amplitudes were greater and more regular than those on the east coast, with distinct spring tides every 14 days.

It seems possible that inanga populations in Westland could utilise the distinct full moon tides, in addition to the higher, new moon tides, and there was some evidence that this was the case. Very active spawning, causing distinct milt discolouration, was observed around the time of the full moon tides on a Waitangitaona tributary (Taylor 1989), and observations of spawning on the Oneone in February 1990 may have taken place on the full moon. However, on the east coast, observations on the Heathcote River at the time of the full moon confirmed that these very low tides were not utilised by spawning inanga (Appendix I).

Benzie (1968) showed that in Benzie's Creek (Canterbury), inanga spawned on either the new or full moon tides, depending on whether the spring tides fell on the new or full moon during the spawning season. Interestingly, in 1960, the spring tides, and inanga spawning, shifted from the new moon to the full moon tides partway through the spawning season.

With two exceptions (the Makawhio and Kaiapoi Rivers), spawning always took place on tides following the new or full moon. There was no overall relationship between the intensity of spawning and the number of days after the new moon, although at any one site and sequence of spring tides, spawning increased in intensity on successive tides, before slowly abating. The best example of successive spawning activity was recorded from Bakers Creek, in the Karamea River catchment. At this location, a relatively low level of spawning activity began two days after the new moon and peaked the next day, before declining over the following two days (Appendix IV). A noticeable fall-off in spawning intensity in Collyer Creek (Turnbull River catchment) took place on falling spring tides, two and three days after the new moon

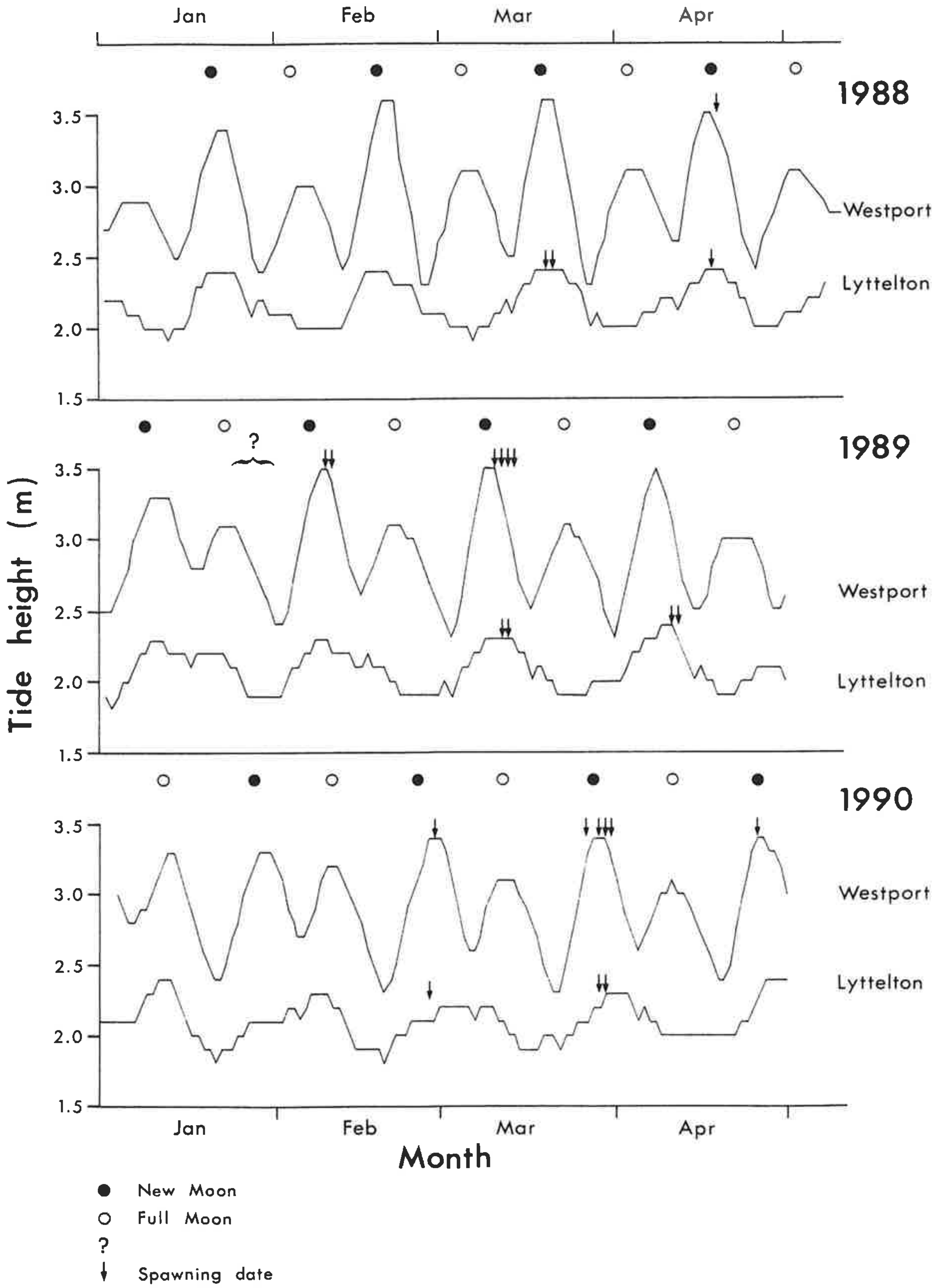

FIGURE 25. Tidal cycles, lunar calendar, and spawning dates for the inanga survey periods. The symbol (↓) indicates when spawning was recorded.

(Appendix IV). Presumably, the difference in spawning activity on successive days reflected the number of ripe fish in the shoal which were ready to spawn on that tide. On many occasions, observers reported shoals of fish disjointed from the main spawning shoal, which did not participate in spawning. These fish may be undergoing the final stages of gonad development prior to spawning on following tides. Benzie (1968) also reported fish aggregating in the spawning area 2-3 days before spawning, but did not elaborate on their behaviour, although she thought that this behaviour facilitated final maturation.

Clearly, spawning is correlated with the lunar and tidal cycles, but some observations indicate that ripe inanga are also rather opportunistic, exploiting elevated water levels for spawning even when they are caused by factors other than tidal or lunar influences, e.g., spawning has been observed on freshes (Makawhio River) and freak tides (Benzie 1968). Conversely, in 1989, wind conditions on Lake Ellesmere depressed normal tidal water levels and prevented spawning on one tide, although spawning took place both on previous and on subsequent tides. It therefore seems possible that the spawning response is induced by rapid increases in water level, and/or flooded shallows, which may or may not be necessarily tidal. On 12.04.89, spawning at Lake Ellesmere was particularly protracted, and was still taking place 3.25 hours after high water. At this time, the stream level periodically rose and fell 30-40 mm, which was probably due to disturbance of the lake level from a southerly storm the day before. This environmental cue may have elicited an extended, weak, spawning response leading to the protracted spawning behaviour.

Pollard (1971) examined the life history of a landlocked population of inanga in an inland lake in Victoria, Australia. He found that the population spawned in late winter/early spring, which allowed the developing larvae to feed on the summer plankton bloom and to grow quickly with the elevated summer water temperatures. Interestingly, the fish spawned in ephemeral lake tributaries which flooded in late winter, but were dry at other times of the year. Consistent with our observations, Pollard reported communal spawning in sheltered shallows, away from the main current. In his study, eggs developed amongst the vegetation between flood events, which could be separated by as little as two weeks, or as long as a month. He hypothesised that the increased water flow acted as the stimulus to spawn. Spawning by other freshwater fish (cyprinids and dace) has been linked to flooding and an accompanying increase in water temperature, oxygen concentration, and possibly pH (Hora 1945).

4.1.3 Tidal Cycle

Hayes (1932) made the following comments about inanga spawning:

> "*As soon as it* [the tide] *has reached its highest level but not before, and usually some minutes or possibly as much as an hour after high water, the fish make their way among the herbage, swimming or wriggling in the inch or two of water covering the ground. Spawning occurs almost always after the turn of the tide, sometimes at the peak, but never before the tide had reached its full height.*"

From our data, excluding Lake Ellesmere, spawning commenced, on average, 33 minutes after the tide had peaked, although there was considerable variability, even between spawnings on successive days at the same site. Spawning was observed on the Karamea River for four days in succession. On the first day of observation, spawning began 75 minutes after high water, but then started 10 minutes, 17 minutes, and 6 minutes after high tide on the 2nd, 3rd, and 4th days, respectively. One hypothesis to explain why inanga spawn closer to the time of high water on lower spring tides is to ensure that the eggs are deposited sufficiently high out of the water, and are therefore safe from floods. Alternatively, the eggs deposited on the previous tide may stimulate further spawning at the same location. Observations from the Turnbull River, south Westland, also suggest that spawning may start sooner after high water on successively lower spring tides. Regrettably, time and staffing restraints meant that spawning observations on successive tides were not as frequent as we would have preferred.

4.1.4 The Saltwater Wedge

Captain L. Hayes first reported whitebait spawning in the "tidal water on the Manawatu River" (Hefford 1933), and later studies indicated that spawning took place near the saltwater wedge, i.e., the junction of tidal sea water and riverine fresh water (Benzie 1968). There are many examples of spawning either side of the saltwater wedge. Mitchell (1990a) found that spawning sites on the Waikato River were all upstream of the saltwater limit. In Canterbury, spawning usually took place within 100 m downstream of the wedge's termination, and in Westland spawning was normally found just upstream of the wedge (Appendix IV). It is presumed that shoals of ripe inanga detect the change in salinity, and that this acts as a cue for locating suitable spawning sites, either upstream or downstream. There are early records of spawning above the tidal influence when river levels were raised by a fresh, e.g., in the lower reaches of the Turanganui River, which feeds Lake Onoke, Wairarapa (Hefford 1933). However, the lower reaches of this river are currently brackish and tidal (Wellington Regional Council pers. comm.).

There are some notable exceptions to spawning near the saltwater wedge. Spawning on the Heathcote and Avon Rivers took place well upstream of the saltwater intrusion, and, in the case of the Heathcote River, was 1.5 km upstream of the saltwater wedge (G. A. Eldon pers. comm.), although Knox (1973) recorded brackish water well upstream of the extinction of the saltwater wedge. Since publication of Knox's report, the Woolston Cut, a diversion which has significantly reduced the length of the river, has probably allowed salt water to intrude much further upstream. Similarly, on the Avon River, Knox (1973) recorded brackish water to the Avondale Road bridge, where inanga spawning took place, although the saltwater wedge terminated at Bridge Street, 5 km downstream. Salinity readings taken on the spring tide of 20.03.88 support these data. Inanga migrating downstream could probably detect the brackish water well before the saltwater wedge.

Lake Modewarre, where Pollard (1971) made his study of landlocked inanga stocks, is brackish, although he also knew of other Australian landlocked freshwater lakes containing inanga. Further, in New Zealand, a species closely related to inanga, the dwarf inanga (*Galaxias gracilis*), lives and breeds in Northland dune lakes without access to salt water.

Spawning habitats also were found in systems where no saltwater wedge formed at all. These locations occurred on the banks of streams feeding large, shallow estuaries and lagoons, where wind-mixing prevented formation of a saltwater wedge. Nevertheless, creeks and rivers which drained into these systems were utilised for spawning, e.g., Lake Ellesmere and Rakaia lagoon. At Boat Creek, a very short, spring-fed stream draining into Rakaia lagoon, observations revealed that most spawning inanga migrated from other areas of the lagoon; inanga swam upstream from the brackish water into fresh water, prior to spawning. In Lake Ellesmere there was no salt wedge, although the water is brackish owing to its close proximity to the sea. No observations were made on the origin of spawning fish, but it is likely that at least some of the mature fish swam downstream from the swampy habitat at the stream source, although many were likely to have arrived via the lake.

In conclusion, although spawning inanga often were located near the salt wedge, an abrupt change in salinity may not be required to stimulate spawning. Rather, a small salinity change may be sufficient to cause the shoal to search for suitable spawning sites. Our data show that spawning inanga can approach the boundary of fresh and saline water from either upstream or downstream of the interface, which, in some habitats (e.g., Boat Creek) means swimming upstream a short distance to spawn. Spawning may take place some distance from the limit of saltwater intrusion, and this may be because there are no suitable spawning locations closer to the wedge, or that spawning shoals have failed to locate all potential sites.

4.2 Biotic Factors Affecting Spawning

4.2.1 Riparian Vegetation

Benzie (1968) summarised the requirements for egg development to be protection, water supply, and facilities for gas exchange. Dense riparian vegetation plays a critical part in meeting these requirements, by generating a humid, temperature-moderated micro-environment for egg development, protected (at least in pre-European times) from predators. It was clear from the results of this and previous studies that inanga eggs were associated with vegetation that formed a thick mat just above soil level, which presumably provided the best micro-environment for egg development.

In most modified riparian habitats, native vegetation along waterways has been replaced with exotic grasses and trees. Spawning inanga evidently have adapted well to using this ecologically more aggressive, exotic vegetation, which has displaced native plant species almost completely from the intertidal lower reaches of streams and rivers (Meurk undated b). North Island inanga spawning ground surveys have indicated that pasture grasses also are used for spawning (Mitchell 1990a,b), and almost every spawning site in the Bay of Plenty was grazed during the spawning season (Mitchell 1990b). Mitchell (1990b) claimed that the limited spawning grounds in the Bay of Plenty represent a "bottleneck" for the inanga population. On the mainstem of the Waikato River, many spawning ground plant communities consisted of flax, parataniwha, and wandering Jew, often under a canopy of alder trees. Sites comprising grasses palatable to stock were present, but, owing to widespread cattle trampling and grazing, these sites were generally unsuitable. A major spawning site (Okahu Stream), discovered in 1983, has since been grazed and trampled by stock, and is not now used for spawning.

Exotic grasses seem to be adequate for spawning only when of sufficient height and density to retain moisture at the litter layer level. Some common exotics are pre-adapted to providing suitable spawning habitat. For example, creeping bent and creeping jenny develop horizontal runners which form a thick, moisture-trapping network just above the soil layer, and their fine root hairs provide a large surface area for egg deposition. The leaves of tall fescue can grow to about a metre in length, before eventually decaying around the base to form a dense mat which traps moisture.

Willow trees commonly are found along riparian margins in developed catchments, and it was observed that inanga preferred to spawn in grasses between willows, rather than under their canopy. The aversion of spawning inanga for heavily willowed areas was recorded in Captain Hayes' pioneering work in the 1930s (McDowall 1990). It is probably due to thinner grass growth under the willow canopy because of shading, and it is possible that spawning could take place under willows if a suitably shade-tolerant, thickly growing understorey was available. Mitchell (1990a) reported high egg counts amongst wandering jew which grew profusely under a canopy of black alder. Plants indirectly of benefit to inanga spawning were the noxious weeds: gorse, blackberry, and to a lesser extent, broom. These species formed thickets which limited or prevented potentially damaging stock access to many spawning grounds bordering pastoral land.

The percentage of spawning locations that comprised largely exotic vegetation was higher in Canterbury than in Westland, which reflects the intensive and extensive development of pasture lands and riparian environments on the east coast. Westland spawning locations had a high proportion of mixed vegetation, i.e., about equal proportions of exotic and native plant species. Meurk (undated a) commented on the remarkable penetration of vigorously growing exotic species along river margins, even in areas of otherwise unmodified indigenous vegetation.

Observations on the Heathcote River indicated that preferred spawning areas changed when the riparian vegetation was modified. No spawning occurred upstream of Wilson's Road bridge after the bank grass was mown down to soil level, even though quite high egg concentrations were found along this reach prior to grass cutting. A less dramatic example was found on a tributary of the Waitangitaona River, where preferred spawning sites changed from clover- based sites in 1989, to browse-resistant *Carex* and flax sites in 1990, after bankside soft grasses had been grazed.

Inanga spawning in the Turnbull River system provided one of the few examples of spawning amongst almost completely indigenous vegetation. Even here, exotic species had invaded the riparian margins to a surprising extent. Eggs were found in the leaf litter and soft grasses which grew around the bases of flaxes, sedges, and rushes. Owing to their resistance to shear stress, the blades of flaxes protect the accumulated leaf litter and grasses from being washed away when the spring tides inundate the bases of these plants. When the tide comes in, the litter layer delaminates slightly, allowing ripe inanga to spawn under and amongst the moist rotting humus (Meurk 1990). Prior to invasion by exotic species, the Westland riparian vegetation accessible to spawning inanga would have comprised an overstory of trees and scrub, specifically kowhai, pate, manatu, kahikatea, native broom, tree tutu, putaputaweta, ti kouka, and other forest trees. An understorey of tall tussocks and shrubs would have consisted of harakeke, tussock sedges, mikimiki, koromiko, wiwi, oioi, and kiokio. Amongst this dense, tall vegetation, a growth of soft turfy sedges (purei), spike sedge, and various herbs and mosses would have maintained high humidity over roots and trapped leaf litter (Meurk undated b).

It is noteworthy that, prior to the advent of routine stream dredging, many of New Zealand's waterways were choked with emergent flaxes and raupo. A present-day example of this type of habitat had developed on Waikewai Creek, in the Lake Ellesmere catchment, where the stream delta was covered in emergent raupo. Inanga spawned amongst the moist, decomposing raupo leaves and flower heads which layered the soft, wet substrate amongst the vertical raupo stalks. Regrettably, these beds were largely destroyed by the Regional Council, to facilitate upstream wetland drainage. Prior to European channelisation, emergent vegetation of this nature, with trapped beds of litter below, may have provided ample instream spawning habitat, and inanga spawning may not have been limited to watercourse banks, as it is today.

4.2.2 Site Selection

Throughout this study, it was apparent that, within an extensive area of suitable, accessible, and apparently similar vegetation, inanga would select and spawn communally only in specific areas during a set of spring tides. Benzie (1968) also noted this phenomenon in her Saltwater Creek study. She hypothesised that access (determined by tide height) may, in part, determine the specific spawning site. She observed that the highest egg densities were in areas with the easiest access.

When access to pasture was possible during the 1962 flood tides, inanga spawned there, but these eggs were left stranded when the flood subsided.

In this study, it was apparent that many spawning sites were found in bank embayments, backwaters, or at stream confluences, away from the direct current. At these locations, shallow bank gradients allowed relatively easy access by inanga to broad swathes of suitable vegetation. Spawning in shallow, sheltered water probably serves to concentrate milt over the eggs, thereby facilitating fertilisation. Further, sheltered tributaries, backwaters, and confluences are less likely to be exposed to flood waters (and consequent egg loss) than those in mainstream locations. Communal spawning in general is probably a behavioural adaptation to maximise egg fertilisation for a population. Such behaviour evolved in habitats without many of the predators and riparian modifications introduced by the European.

There were many occasions in this study when large spawning sites discovered during surveys in previous years were found later to have been ignored for spawning. Large shifts in preferred spawning sites could not be explained by annual variations in the saltwater wedge. This suggests that spawning inanga are not particularly specific about the spawning location (apart from access, change in salt concentration, and luxuriant plant growth) when there is a large area of potential habitat. Thus, where spawning inanga have access to numerous potential spawning sites, the location of chosen spawning areas may vary considerably from year to year. In contrast, if an extensive area of adult inanga habitat is drained by a single stream, then spawning inanga will be more confined in their search for suitable habitat, and are more likely to utilise the same reaches for spawning. For example, Benzie's Creek is a small stream, with a relatively large area of adult inanga habitat compared to the area available for spawning (which is limited by grazing and willowed banks). Therefore, it is not unexpected that inanga spawn along the same reach from year to year.

The fact that precisely the same spawning sites are utilised on any one set of spring tides suggests one of two possibilities. Firstly, successive spawning shoals on each spring tide may discriminate and re-select the exact spawning site from less suitable areas, based on a set of highly specific and consistent environmental criteria. Alternatively, spawning sites may be selected only once, early in the spring tide sequence, and once chosen are either "tagged" in some way, or the spawning fish are imprinted to facilitate site location on later tides.

The first possibility seems unlikely, because of the large duplication of effort required by the shoal, and the implausible conclusion that they would find exactly the same site on successive tides. Further, as the number of spawning inanga noticeably increases on successive spring tides, imprinting seems unlikely, as many fish on later tides would not have been to the site previously. The second possibility, that inanga "home" onto a pre-selected site, seems more plausible, particularly in light of observations of inanga displaying exploratory behaviour on the spring tides prior to spawning. At two locations (Heathcote River and Bradshaws Creek, Buller River), two days before spawning took place, large schools of ripe fish were observed scouting the banks on the spring tides. Then, a day prior to spawning, inanga shoals swam amongst the emergent vegetation at the location in which they spawned on the following spring tides. Exploratory behaviour also was recorded from the Avon River, at the precise location where eggs were found at a later date. Similarly, Benzie (1968) reported inanga congregating in the spawning area 2-3 days before spawning.

Our observations of pre-spawning fish in close proximity to sites where they later spawn, suggest that spawning sites may be selected on tides prior to those when spawning takes place. During the exploratory phase, the inanga must either become imprinted with the locality, or the site must be biochemically labelled by a pheromone to attract spawning shoals on later tides.

Imprinting seems unlikely, owing to the short time (approximately 40 minutes) that inanga are exposed to the prospective spawning site. Mitchell (pers. comm.) found in laboratory studies that, when spawning site turf was placed side-by-side with identical turf which had not been used for spawning, ripe inanga ignored the unused turf. Therefore, spatial cues alone do not determine spawning.

The congregation of ripe fish amongst emergent vegetation may stimulate pheromone release by the shoal, or, alternatively, if the fish are running ripe, to shed milt or ova which could act directly as the homing agent. The riparian vegetation would then become "labelled" as the tidal water receded, at least until the following spring tide. In this study, there were some field observations which support this pheromone-homing hypothesis. Inanga were observed spawning along the mainstem of the Poerua River, on highly unsuitable substrates. Fish were beaching themselves on steep river gravels during the falling tide, apparently in an attempt to reach grasses just above the water line. Inanga also were attempting to spawn on the surface of a largely submerged punga log which had fallen into the water nearby. Spawning on such unsuitable surfaces could be a response to the attraction of a pheromone leaching out of the grasses, across the gravels, and into the surrounding water. Higher water levels on previous spring tides would have allowed pre-spawning fish access to the riparian grasses. The literature records pheromones eliciting homing behaviour in Atlantic salmon (Johannesson 1987).

In summary, it is possible that inanga are not highly site selective in respect to spawning microhabitat, except that there must be sufficient vegetation to maintain high humidity, and the site preferably must be sheltered from the current and accessible by tidal waters. However, once a spawning site is chosen and biochemically labelled, it is used to the exclusion of other areas.

4.3 Impacts on Spawning Grounds

It is important to consider that most of the spawning grounds found in this study were, at the time of writing, under direct or indirect threat from a variety of human activities (Table 1).

4.3.1 Vegetation Damage by Stock

Stock affects inanga spawning in two major ways; firstly, by grazing the vegetation over spawning areas to the point where humidity around the eggs cannot be maintained and, secondly, by trampling eggs deposited amongst the vegetation. Pollution and local sedimentation caused by bank damage also may reduce the suitability of the vegetation for spawning.

Benzie (1968) examined egg mortality in grasses that had been grazed by cattle. She found that eggs only died through desiccation during very hot periods, and that inanga eggs could tolerate a loss of turgidity for up to two days. Further, inanga eggs are remarkably tolerant of high temperature fluctuations, as Benzie recorded a diurnal temperature change of 5-18°C amongst eggs at Benzie's Creek (Benzie 1968). Benzie also reported that egg development is temperature labile, with a three-fold decrease in egg development time between eggs incubated at 4.4°C (31 days) and at 17°C (10 days). Therefore, any deleterious effect on inanga eggs brought about by a reduction in vegetation due to stock grazing results from a long-term reduction in air humidity, rather than an adverse increase in egg temperature or diurnal temperature range. Aside from the effects of trampling, cattle grazing probably causes egg mortality only in very hot weather, although spawning ground aspect and other local climatological factors may also have a major influence. The spawning sites in Benzies's study were shaded by trees, and strong sunlight may have an adverse effect. The effects of sheep grazing are unknown, although it is likely that eggs are even more likely to desiccate, because sheep crop grass more closely and intensively than cattle.

Mitchell (1991) recorded large differences in inanga site preference and egg mortality between grazed and ungrazed (fenced) sites on the Kaituna River. After an area of stream bank was fenced from livestock for 18 months, inanga spawning, which was previously uniform along the reach, became concentrated in the fenced section and was negligible in the grazed section. Egg survival estimates, based on implanted, artificially-spawned eggs, were higher in the ungrazed section, some exceeding 50%, whereas the best survival in the grazed section was less than 25%. Interestingly, survival in both sections was vastly improved by covering the implants with 1 mm nylon mesh. Mean survival increased from 1.6% to 54% in the grazed section, compared to an increase from 0.7% to 44% in the ungrazed area.

Benzie (1968) illustrated how sensitive eggs were to physical damage when she reported that, even when eggs were gently pipetted or manipulated with a fine paintbrush, they were attacked by *Saprolegnia*, a common soil fungus. Eggs left in situ on the original turf showed no such infection. Close examination of the affected eggs revealed that their outer adhesive layer was disrupted, and Benzie surmised that the outer layer has an antibiotic function, in addition to providing a holdfast. In the natural state, eggs are laid in very high concentrations over a limited area, and it is possible that, in such a humid environment, fungal infection could spread quickly through an egg mass. Fungal infection may also have contributed to the high egg mortality amongst artificially spawned and deposited eggs in Mitchell's Kaituna River study. Thus, trampling of vegetation by stock is likely to have severe consequences to egg survival because of mechanical damage to the eggs, either by direct crushing or by facilitating fungal infection.

Direct evidence of spawning ground damage by pigs was observed on Benzie's Creek during the summer of 1989. At this time, about four sows and their litters were fenced into most of the area in which inanga were known to spawn. Extensive damage caused by rooting and ground pugging was evident, and eggs were found only in an area fenced off from stock. Last season (1990), after notifying the Canterbury Regional Council of the problem, the pigs were removed and the spawning ground allowed to revegetate.

TABLE 1. Threats to known inanga spawning grounds.

Catchment	Locality	Impact details
Saltwater Creek	Benzie's Creek	Farrowing, trampling by pigs
Kaiapoi River	Mainstem	Water pollution, boat wash
Avon River	Avondale	Riparian grass mowing
Heathcote River	Wilsons Road	Duck predation, formerly mowing
Lake Ellesmere	Waikewai Creek	Destroyed 1990 by channelisation
Rakaia River	Boat Creek	Cattle grazing/trampling
Rakaia River	Mathias Creek	Potential stock access
Oparara River	Northern drains	Drain clearing/cleaning
Karamea River	Bakers Creek	Access by cattle
Karamea River	Granite Creek	Drainage of upstream habitat
Buller River	Drain at yacht club	Polluted by fuel oil, dumped gravel
Buller River	Bradshaws Creek	Trampling and grazing by stock
Grey River	Cobden Island	Pollution from rubbish, landfill, and sewage
Hokitika River	Mahinapua Creek	Siltation due to gold mining discharge
Waitanitaono River	Near DOC hut	Stock grazing/trampling
Manakaiaua River	Sam Creek	Stock grazing/trampling
Turnbull River	Collyer Creek	Stock grazing/trampling

4.3.2 Draglining and Channelisation

During May 1990, Waikewai Creek was dredged with a mechanised trenchdigger, comprehensively destroying the riparian and macrophyte vegetation. The stream bank on one side was extensively crushed, and slumped because of the weight of the digger, and riparian vegetation (emergent raupo) was dredged from the far bank, across the stream bottom, and dumped on the bank near the dredger, along with much of the fine material from the stream. The debris, which consisted of raupo, stones, mud, and numerous decapitated eels, covered the existing spawning ground to a depth of about 0.5 m (Fig. 26). At the time of writing (October 1991), the spawning site had not recovered from this operation. Davis (1987) identified Lake Ellesmere as a wetland of national importance, and a National Water Conservation Order to protect the lake has since been gazetted. However, the primary focus of the conservation order is to protect wildlife habitat by setting maximum and minimum lake levels, and, despite the Order, the inanga habitat has been devastated.

Draglining and channelisation are an anathema to fisheries values, and indeed to ecological values in general. The destruction wrought by these management techniques has had severe, longlasting effects nationwide. McDowall (1975) cited swamp drainage, development, and the reclamation of estuaries amongst the most serious contributors to the decline in the whitebait fishery. Channelising leads to oversteepening of the stream banks, which, even if grassed, reduces the available spawning area to a minimum. Enhanced drainage and insolation also lowers the humidity near soil level. Initially, inanga eggs can still adhere to vegetation hanging over a steepened bank, but our observations show that they are prone to being washed away by freshes or other spring tides. This situation has occurred on the Heathcote River in the steep section above Wilsons Road bridge. If channelisation occurs on a broader scale, then the reduction in fish cover (stream vegetation) may severely limit the amount of inanga habitat in a system, and numbers of spawning fish will be reduced substantially. An acceleration of bank erosion often follows oversteepening of bank profiles, and the banks then have to be shored. On the Avon River, the stone cladding in the lower reaches restricts the area that inanga can use for spawning.

In urban settings, at least in Christchurch, rivers and their banks are important recreational areas, maintained by the City Council. The Council has sown the river margins with grass, which is then regularly mown by gangmower to about 40 mm in height, for the sake of appearance and the convenience of pedestrians. Inanga will not spawn in grass that has been mowed, and eggs deposited prior to grass cutting die through desiccation. Fortunately, recent changes in riparian management policy by the Christchurch City Council will allow greater vegetation growth along the river margins.

4.3.3 Tide Gates and Culverts

Tide gates and culverts are impediments to inanga migrating to spawning grounds. Eldon (1988a) identified four options if closed tide gates on the Titiroa Stream prevented inanga from migrating to the spawning area. Firstly, affected fish could wait until the spring tide had fallen, then swim through the gates and spawn on the next spring tide. Secondly, if the gates opened sufficiently early, inanga could spawn downstream on the remaining ebb tide. Thirdly, if suitable habitat was not available downstream, inanga may have to search for spawning habitat upstream of the gates, and therefore risk having their upstream passage impeded by the gates closing on the rising tide. Fourthly, if migrating inanga were impeded by tide gate closure, they could simply spawn upstream of the gates. Eldon theorised that impeded inanga shoals could suffer increased predation from other fish and from whitebaiters. Moreover, if eggs were laid upstream of the gates, where water levels are strongly moderated, then eggs could be prone to regular inundation and thus to predation by aquatic organisms. Inundation alone does not cause egg mortality (Benzie 1968).

The Styx River in Canterbury has tide gates which effectively prevent the salt wedge and the incoming tide from intruding further upstream (FFC unpublished data). No spawning sites have been discovered above these gates, despite ample suitable spawning habitat and exhaustive searches. To date, there has been only one record of a spawning site above a flood/tide gate, and that was on Blackwater Creek, in the Karamea River catchment. From a management perspective, it would be illuminating to discover when inanga upstream of these gates spawn, compared to those downstream, and to compare egg mortality for sites above and below the barrier.

FIGURE 26. Riparian damage caused by a dredge digger on Waikewai Creek, Lake Ellesmere.

4.3.4 Management Options to Enhance and Protect Spawning Grounds

4.3.4.1 Berm Fencing

By preventing stock access, streamside (berm) fencing is the most effective way of maintaining the quality of inanga spawning grounds. As spawning is seasonal and site specific, temporary fencing from December through to May would suffice, but a good permanent fence would probably require less maintenance in the long term.

There have been some difficulties in protecting spawning habitat where the spawning grounds are on private land. One landowner, despite being informed of the spawning ground and observing inanga spawn, still permits stock access. To alleviate this problem, DOC are purchasing electric fencing equipment on a regional basis. Alternatively, and preferably, local community pressure to maintain or enhance the whitebait fishery may be an effective tool to ensure spawning ground protection.

4.3.4.2 Curtailment of Bankside Mowing

In urban environments, local authorities can be approached to retain riparian vegetation for inanga spawning. Consultation with the Christchurch City Council has led to the exclusion of grass mowing from the whitebait spawning area on the Heathcote River, at least during the spawning season. Signs have been erected along each bank, explaining that bankside grasses are left uncut for inanga spawning (Fig. 27). There was some negative reaction from one local resident, who simply did not believe that spawning occurred at all! (G.A. Eldon pers. comm.). However, the venture has proved to be successful, with good grass growth providing spawning habitat for future seasons.

Since a section of the lower Heathcote River was set aside for replanting in native vegetation, inanga have begun to spawn along the grassed bank margins, which have remained uncut since the project began in 1990. Since the project's inception, the area has been clearfelled of willow, which previously lined the banks, and many native trees and shrubs have been planted by community groups and by the City Council. Unmown riparian grass now lines the banks, in which inanga spawn, whereas prior to commencement of the project, spawning did not occur along this reach of the river.

4.3.4.3 Replanting of Native Vegetation

Replanting spawning areas in native vegetation is the most time-consuming and probably most expensive option for enhancing whitebait spawning. However, in many ways, it is probably the best, because completely native riparian plant communities are now very rare (Meurk undated b) and much can still be learnt about inanga spawning in these habitats. The easiest way to establish such a site would be to start with an area where there is already as much native vegetation as possible, and selectively remove the exotic species. A maintenance programme would be required to prevent recolonisation by exotic plants. Alternatively, if only sites with introduced grasses were available, the native habitat may have to be completely developed from scratch. These new communities will take some time to mature, and will require botanical expertise on native plant communities, associations, and succession. To develop a permanent, representative plant community, it is desirable that only local varieties and strains of native species are used. The Botany Division of the Department of Scientific and Industrial Research can provide advice on suitable plants. Attention should be paid to the bank profile, to ensure that there are shelved, thickly vegetated areas which are flooded on the spring tide for spawning to occur. Irregularities in the banks, creating back eddies, and gently shelved sections at the confluence of streams also are conducive for spawning. In an urban setting, such areas could provide education on the native biota for schools and interest groups.

Mixed plant communities of exotic and native flora are quite suitable and easily maintained. Stream margins could consist of tall *Festuca* grass and flaxes, with a native tree and shrub canopy. Exotic grasses provide excellent spawning habitat and exclude colonisation by less suitable adventives. Fencing may be required to protect the stream margins from stock damage. Care should be taken that noxious exotic weeds are not promulgated, and, contrary to the recommendation of Mitchell and Eldon (1990), wandering jew should <u>not</u> be used to restore spawning habitats.

4.3.4.4 Publicity

In the past, the public and local authorities generally were ignorant of the requirements for inanga spawning, and even more so of the whereabouts of local spawning grounds. The situation regarding local authorities has improved markedly in Canterbury over the course of this study. Further, in our experience, when members of the public are informed of the interesting spawning behaviour of inanga, they almost always respond positively to the idea of conserving spawning grounds.

FIGURE 27. Bankside sign at the Heathcote River inanga spawning site.

Publicity of the existence of spawning grounds and their environmental sensitivity would be beneficial. So far, we know of at least two instances where a lack of communication has led to spawning ground damage. Firstly, diesel oil pollution of the Westport spawning ground could have been prevented had the public known of its existence. Secondly, damage to the Lake Ellesmere spawning ground by a dredge digger may have been minimised had the local council been aware of the problem. Informing local councils, and erecting permanent signs pointing out the sensitivity of the area, may go a long way in reducing this problem. It is acknowledged that publicity can become a problem in itself by attracting the attention of people who could intentionally damage the habitat, or, more likely, unintentionally trample the site while looking for eggs. However, the Heathcote River spawning site has remained unmown by the Council and untrampled by the public for two years, and the two permanent signs have suffered only minor vandalism.

On private land, the issue of habitat conservation must be handled diplomatically, and some advantage can be gained by stressing how landowners can play an important part in enhancing the whitebait fishery. Some follow-up work with unco-operative landowners may be required, to ensure that stock are kept off spawning sites. Publicising local whitebait catches may encourage community support for spawning ground conservation.

Other options are to set up reserves, obtain local land covenants, lease land, and exchange or purchase small areas of land.

4.3.4.5 Database Development

To facilitate management and research on whitebait spawning, the FFC's national Freshwater Fish Database is to be used to store inanga spawning site records. A special inanga spawning survey form has been designed (Appendix XIV), and agencies will be encouraged to send in completed forms to MAF Fisheries. The form should be used in conjunction with the waterproof FFC publication entitled "How to Locate and Protect Whitebait Spawning Grounds" (Mitchell and Eldon 1990), and photographs also may be sent in with the completed form. It is intended that summaries of regional and national spawning site data will be made available to DOC conservancies when they receive their six monthly update from the Freshwater Fish Database.

5. RECOMMENDATIONS

1. That there is increased liaison between DOC and those responsible for riparian maintenance, to

ensure the conservation of inanga spawning grounds.

2. That spawning sites accessible to the general public be signposted to explain the sensitivity of the area.

3. That stock be excluded from spawning grounds, at least from December through to the end of May.

4. That enhancement of existing spawning grounds be carried out, where necessary, by replanting with rushes, tussocks, and grasses found in the locality. In channelised urban environments, excavation of embayments and reduction of bank gradients may prove beneficial.

5. That further work be carried out on the effects of tide gates on whitebait spawning, to ascertain how these effects can be ameliorated.

6. That a centralised database be maintained, recording the location and nature of whitebait spawning areas, to facilitate whitebait research and management.

7. That research be undertaken on how the timing of downstream migrations relates to the timing of spawning behaviour within river systems, and on the management implications of repeat spawnings by previously spawned fish.

8. That further survey work be carried out in new areas to establish the extent of whitebait spawning areas nationally.

6. ACKNOWLEDGEMENTS

Firstly, we would like to thank the numerous people who assisted us in the field: John Green, Paul Coles, Don Dixon, Barry Chalmers, Jenny Brown, John Reid, Chris Woolmar, Mike McIvor, Martin Abel, Chris Pugsley, Angus Handisides, Tony Cunningham, Barry Hanson, Stephen O'Dey, Glen Crickett, Glen McDonald, Norman Stopforth, Ian Hadland, and Peter Foord (all from DOC), and Marty Bonnett, Tony Eldon, Eric Graynoth, and Don Jellyman (from the FFC). Our appreciation also is extended to all other DOC staff who assisted in the field.

Special thanks go to Colin Meurk for identifying numerous plants and shrubs in the field, and expert advice on riparian vegetation and its management. Don Jellyman, Tony Eldon, Eric Graynoth, and Colin Meurk assisted in reviewing the manuscript, while Sally Davis and Carol Whaitiri were responsible for editing and formatting, respectively.

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APPENDIX I. Summary of inanga spawning surveys, 1988-1991.

Date	Catchment	Survey site	Spawning observed	Eggs found	No. of sites
22.01.88	Ashley	Benzie's Creek	+	+	6
22.01.88		Saltwater Creek	+	-	
26.01.88		Saltwater Creek	-	+	10
19.03.88		Benzie's Creek	+	nd	
19.03.88		Lagoon tributary	+	-	1
17.02.88	Styx	Below, at, above tide gates	-	-	
19.02.88		Above tide gates	-	nd	
16.05.88		Below floodgates	-	-	
26.02.90		Above gates	-	-	
27.02.90		Below gates	-	-	
16.02.88	Waimakariri	Stream near McIntosh's Rocks	-	-	
18.02.88		Brooklands Lagoon	-	-	
22.02.88		Stream near McIntosh's Rocks	-	-	
20.03.88		Kaiapoi River mainstem	+	+	1
17.04.88		Kaiapoi River mainstem	+	-	1
20.03.88	Avon	Kerrs Reach-Brighton bridge	-	-	
09.04.89		Stanmore Road-Porritt Park	-	-	
10.04.89		Avondale bridge (some shoals)	-	-	
21.04.89		Avondale bridge	-	+	8
27.02.90		Avondale bridge	+	nd	
16.05.91		Avondale bridge	-	-	
17.05.91		Avondale bridge	-	-	
09.03.89	Heathcote	Malcolm Ave-Brownbrae Ave	-	-	
10.02.89		Wilsons Road (some shoals)	-	-	
11.02.89		Wilsons Road	+	-	4
15.02.89		Wilsons Road	-	+	
21.02.89		Wilsons Road (full moon tide)	-	-	
22.02.89		Wilsons Road (full moon tide)	-	-	
11.03.89		Wilsons Road	+	nd	
12.03.89		Wilsons Road (minor spawning)	+	nd	
12.03.90		Wilsons Road (full moon tide)	-	-	
13.03.90		Wilsons Road (full moon tide)	-	-	
30.03.90		Wilsons Road	-	-	
25.04.90		Wilsons Road	-	-	
27.04.90		Wilsons Road	-	-	
28.04.90		Wilsons Road	-	-	
30.04.90		Wilsons Road	-	-	
27.02.91		Wilsons Road (pre-spawning?)	-	-	
19.04.91		Wilsons Road	-	-	
20.04.91		Wilsons Road	-	-	
19.04.91		Aynsley Terrace	+	+	4
20.04.91		Aynsley Terrace (minor spawning)	+	+	

Date	Catchment	Survey site	Spawning observed	Eggs found	No. of sites
08.02.89	Lake Ellesmere	Waikewai Creek (many inanga)	-	-	
14.03.89		Lake margins	-	-	
14.03.89		Waikewai Creek	nd	+	
05.04.89		Waikewai Creek	nd	+	
10.04.89		Waikewai Creek (minor spawning)	+	nd	1
11.04.89		Waikewai Creek (low water level)	-	+	
12.04.89		Waikewai Creek	+	nd	4
29.01.90		Selwyn River delta	-	-	
??.05.90		Waikewai Creek (post-dredging)	-	-	
22.03.88	Rakaia	Lagoon inlets	-	-	
18.04.88		Mathias Creek	-	-	
10.04.89		Lagoon inlets	-	-	
11.04.89		Lagoon inlets	-	-	
12.03.90		Mathias Creek	-	-	
26.03.90		Boat Creek	-	-	
28.03.90		Boat Creek	+	+	7
29.03.90		Mathias Creek	+	+	1
29.03.90		Boat Creek	+	+	
30.03.90		Mathias Creek	-	+	
		Boat Creek	-	-	
30.03.90	Oparara	Farm drains	+	nd	5
10.03.89	Karamea	Bakers Creek mainstem	+	nd	
11.03.89		Bakers Creek mainstem	+	nd	
12.03.89		Bakers Creek mainstem	+	+	9
13.03.89		Bakers Creek mainstem	+	+	
05.04.89		Bakers Creek mainstem	nd	+	
06.04.89		Bakers Creek mainstem	-	-	
08.04.89		Bakers Creek mainstem	nd	-	
12.02.90		Bakers Creek mainstem	-	-	
13.02.90		Bakers Creek mainstem	-	-	
14.02.90		Bakers Creek mainstem	-	-	
26.03.90		Bakers Creek mainstem	-	+	
12.02.90		Karamea River mainstem	-	-	
13.02.90		Karamea River mainstem	-	-	
13.03.89		Karamea River mainstem	-	+	1
06.04.89		Granite Creek (shoals)	-	-	
07.04.89		Granite Creek and tribs. (shoals)	-	-	
14.02.90		Granite Creek	-	-	
28.03.90		Granite Creek (many fish)	-	-	
29.03.90		Granite Creek (intense spawning)	+	+	1
14.02.90		Kongahu swamp drains	-	-	
29.03.90		Kongahu swamp drains	+	nd	2
28.03.90		Blackwater Creek	-	+	3
27.03.90	Little Wanganui	Lower reaches	-	-	
16.10.89	Orowaiti	Railway-Excelsior bridges	-	-	
16.01.89		Beaton Creek	-	-	
16.01.89		Tidal creek at rubbish dump	-	-	
16.01.89		Deadmans Creek-Black Creek	-	-	
09.02.89		Railway-Excelsior bridges	-	-	

Date	Catchment	Survey site	Spawning observed	Eggs found	No. of sites
16.01.89	Buller	Saltmarsh	-	-	
16.01.89		Mainstem tidal creek	-	-	
16.01.89		Bradshaws Creek, downstream from Carters Road bridge	-	-	
09.02.89		Bradshaws Creek (shoals)	-	-	
16.01.89		Martin Island Creek tributary	-	-	
16.01.89		Martin Island Creek tributary (two shoals)	-	-	
08.02.89		Martin Island Creek (pre-spawning?)	-	-	
09.02.89		Railway wharf tidal creek	-	-	
10.02.89		Rowing club shed creek	+	nd	2
28.03.90		Bradshaws Creek (shoals)	-	-	
29.03.90		Bradshaws Creek (pre-spawning?)	-	-	
30.03.90		Bradshaws Creek	+	nd	3
01.03.90	Grey	Cobden Island, first channel	-	-	
28.02.90		Cobden Island, first channel	-	-	
27.03.90		Cobden Island, first channel (low lagoon)	-	nd	
28.03.90		Cobden Island, first channel (low lagoon)	-	nd	
29.03.90		Cobden Island, first channel (low lagoon)	+	nd	1
28.02.90		Cobden Island, second channel (sites 1 and 2)	+	nd	2
01.03.90		Cobden Island, second channel (site 3)	+	nd	1
02.03.90		Cobden Island, second channel (sites 2 and 3)	+	nd	
27.03.90		Cobden Island, second channel (high lagoon)	-	nd	
28.03.90		Cobden Island, second channel (high lagoon)	+	nd	
25.04.90		Cobden Island, second channel (high lagoon)	+	+	
30.03.90	Paroa/New River	Lagoon	-	-	
31.04.88	Taramakau	Coastal swamp creek	nd	+	1
19.03.88	Hokitika	Mahinapua Creek, lower reaches (large shoals)	-	nd	
20.03.88		Mahinapua Creek road bridge (large shoals)	-	-	
21.03.88		Mahinapua Creek, downstream of bridge	-	-	
16.04.88		Mahinapua Creek road bridge	-	nd	
17.04.88		Mahinapua Creek road bridge	-	nd	
18.04.88		Mahinapua Creek road bridge	-	nd	
29.04.88		Mahinapua Creek, true right bank	nd	+	4
30.04.88		Hokitika River mainstem	nd	-	
30.04.88		Mahinapua Creek, true left bank	nd	+	4
08.02.89	Waitaha	Wetland drain	-	-	
09.02.89		Ounatai Lagoon Creek	+	nd	2

Date	Catchment	Survey site	Spawning observed	Eggs found	No. of sites
10.03.89	Wanganui	Oneone River, below footbridge	-	nd	
??.02.90		Oneone River, below footbridge	+	nd	8
28.02.90	Poerua	North bank of mainstem	+	nd	1
28.02.90		Hikimutu lagoon	-	nd	
10.02.89	Waitangitaona	Stream near DOC hut	+	nd	2
10.02.89		Mainstem island (minor)	+	nd	2
10.02.89		Mainstem (both sides)	-	+	2
27.04.90		Stream near DOC hut	-	+	2
28.03.90	Manakaiaua	Sam Creek (S78 398526)	+	+	2
27.04.90		Sam Creek (S78 398526)	+	+	
??.??.90		Hunts Creek, side tributaries (large shoals)	-	-	
26.03.90	Makawhio	Papakeri Creek (S78 361496)	+	-	1
26.03.90		Mainstem (S78 364498)	+	+	1
26.03.90		Island channel (S78 361555)	+	nd	1
27.04.90		Mainstem (S78 364498)	-	+	
08.03.89	Waita	Mainstem	-	-	
09.03.89	Turnbull	Mainstem	-	nd	
10.03.89		Mainstem (some shoals)	-	nd	
10.03.89		Collyer Creek (sites 1-4)	+	+	4
11.03.89		Collyer Creek (sites 5-8)	+	+	4
??.05.88	Waihopai	Mainstem tidal reaches	-	-	
??.05.88	Titiroa	Mainstem tidal reaches	-	-	
Total no. of sites					119

+ = eggs or spawning sites discovered.
- = neither eggs nor spawning observed, despite search.
nd = no search for eggs or spawning was conducted.

APPENDIX II. Scientific and common names of plants identified at inanga spawning sites.

Common name	Scientific name
Alder	*Alnus glutinosa*
American horsebane	*Oenanthe sarmentosa*
Arrow grass	*Triglochin striatum*
Blackberry*	*Rubus fruticosus*
Buttercup	*Rununculus* spp.
Buttonweed	*Cotula coronopifolia*
Californian thistle	*Cirsium vulgare*
Canadian pondweed	*Elodea canadensis*
Centella	*Centella uniflora*
Chewings fescue#	*Festuca rubra*
Clustered dock	*Rumex conglomeratus*
Coprosma	*Coprosma* spp.
Crack willow	*Salix fragilis*
Crassula (herb)	*Crassula* sp.
Creeping bent†	*Agrostis stolonifera*
Creeping jenny#	*Lysimachia nummularia*
Creeping cinquefoil#	*Potentilla anglica*
Creeping buttercup#	*Ranunculus repens*
Cutty grass#	*Carex geminata*
Dock	*Rumex neglectus*
Ergamot mint#	*Mentha x piperita*
Golden willow	*Salix alba vitellina*
Gorse*	*Ulex europaeus*
Gypsywort	*Lycopus europaeus*
Harakeke (New Zealand flax)*	*Phormium tenax*
Jointed rush†	*Juncus articulatus*
Kahikatea (white pine)	*Dacrycarpus dacrydioides*
Karamu	*Coprosma robusta*
Kiokio	*Blechnum minus*
Koromiko	*Hebe salicifolia*
Kowhai	*Sophora microphylla*
Lotus (birdsfoot, trefoil)#	*Lotus pedunculatus*
Mahoe	*Melicytus ramifilorus*
Manatu (lowland ribbonwood)	*Plagianthus regius*
Marsh bedstraw	*Galium palustre*
Mercer grass†	*Paspalum distichum*
Mikimiki	*Coprosma propinqua*
Monkey musk#	*Mimulus guttatus*
Moss#	Unidentified species
Narrow-leaved plantain	*Plantago lanceolata*
New Zealand broom*	*Carmichaelia virgata*
New Zealand sedge (club rush)	*Scirpus distigmatosus*
Oioi (jointed wire rush)	*Leptocarpus similus*
Parataniwha#	*Elatostema rugosum*
Pate (seven finger)	*Schefflera digitata*
Pennywort	*Hydrocotyle* spp.
Perennial ryegrass#	*Lolium perenne*
Punga#‡	*Dicksonia squarrosa*
Puniu (prickly shield fern)	*Polystichum veestitum*
Putaputaweta (marbleleaf)	*Carpodetus serratus*
Raupo#	*Typha orientalis*

Reed sweetgrass*	*Glyceria maxima*
Scottish broom*	*Cytisus scoparius*

Common name	Scientific name
Selfheal	*Prunella vulgaris*
Spearmint	*Mentha spicata*
Spike rush#	*Eleocharis acuta*
Starwort	*Callitriche stagnatlis*
Swamp millet#	*Isachne australe*
Tall fescue†	*Festuca arundinacea*
Three square	*Schoenoplectus pungene*
Ti Kouka (cabbage tree)	*Cordyline australis*
Toetoe#*	*Cortaderia richardii*
Tussock sedge	*Carex virgata*
Tussock sedge (pukio, niggerhead)	*Carex secta*
Tree tutu	*Coriaria arborea*
Umbrella sedge#	*Cyperus eragrostis*
Wandering Jew#	*Tradescantia fluminensis*
Water celery (cow parsley)#	*Apium nodiflorum*
Water forget-me-not	*Myosotis caespitosa*
Water pepper	*Polygonum hydropiper*
Watercress	*Rorippa microphylla*
White clover#	*Trifolium repens*
Wiwi (New Zealand rush)†	*Juncus gregiflorus*
Yarrow	*Achillea millefolium*
Yellow flat	*Iris pseudacorus*
Yorkshire fog†	*Holcus lanatus*

* = species which facilitate the protection of spawning ground vegetation. (N.B. Reed sweetgrass contains cyanide compounds which have caused cattle deaths.)
# = spawning has been recorded on this plant.
† = spawning has been recorded frequently on this plant.
‡ = the one record of spawning on punga is highly abnormal.

APPENDIX III. Grid references, vegetation types, and land use recorded at inanga spawning sites in surveyed catchments.

Catchment	Site location	Metric (NZMS 260) map reference†	Vegetation type*	Vegetation class*	Upstream catchment land use	Vegetation profile
EAST COAST						
Ashley River	Benzie's Creek	M34 24861 57712	E	1,6	Pastoral	Yes
	Saltwater Creek	M34 24862 57724	E	1,2	Pastoral	No
	Unnamed tributary	M35 24866 57696	E	1,3	Wasteland	Yes
Waimakariri River	Kaiapoi River mainstem	M35 24835 57576	E	4,3	Wasteland	No
	Kaiapoi River tributary	M35 24835 57575	E	1	Wasteland	No
Avon River	Avondale bridge	M35 24863 57448	M	1,3	Urban	Yes
Heathcote River	Wilsons Road	M36 24818 57393	E	1,5	Urban	No
	Aynsley Terrace	M36 24847 57384	E	1‡	Urban	No
Lake Ellesmere	Waikewai Creek	M37 24856 57035	E	1,5	Swamp/pasture	No
	Waikewai Creek mouth	M37 24587 57054	N	10	Swamp/pasture	No
Rakaia River	Boat Creek	L37 24488 57018	E	1,2	Pastoral	No
	Mathias Creek	L37 24470 57011	E	1	Pastoral	No
WEST COAST						
Oparara River	Swamp drains	L27 24358 59990	?	?	Swamp/pasture	No
	Swamp drains	L27 24359 59989	?	?	Swamp/pasture	No
	Swamp drains	L27 24356 60004	?	?	Swamp/pasture	No
	Swamp drains	L27 24356 60006	?	?	Swamp/pasture	No
Karamea River	Bakers Creek	L27 24356 59957	E	1,3	Pastoral	No
	Karamea mainstem	L27 24364 59947	E	?	Wasteland	No
	Granite Creek	L27 24350 59898# L27 24351 59898	E	1	Pastoral	No
	Kongahu Drain	L27 24350 59898# L27 24350 59895	E	1?	Swamp	No
	Blackwater Creek	L27 24345 59903	M	1,3	Swamp	No
	Blackwater Creek	L27 24344 59902# L27 24343 59901	?	?	Swamp	No
Buller River	Creek at Yacht Club	K29 23934 59393#	E	1,2	Wasteland	No
	Bradshaws Creek	K29 23921 59393	M	1,2	Swamp	No
Grey River	Cobden Island (1st channel)	J31 23622 58614	E	1,3	Swamp/wasteland	No
	Cobden Island (2nd channel)	J31 23624 58611	N	2,3,7	Swamp/wasteland	Yes
	Cobden Island (2nd channel)	J31 23624 58612	E	1,3	Swamp/wasteland	Yes
Taramakau River	Coastal Swamp Creek	J32 23558 58470 (S50/51 4660 6736)	E	1,2,3	Swamp	No
Hokitika River	Mahinapua River, 7 sites					
	Site 1	J33 23420 58288 (S50/51 4506 6540)	M	1,3,2	Swamp	No
	Site 2	J33 23417 58286 (S50/51 4503 6538)	M	1,3,2	Swamp	No
	Site 3	J33 23417 58284 (S50/51 4502 6536)	M	1,3,2	Swamp	No
	Site 4	J33 23416 58283 (S50/51 4501 6535)	M	1,3,2	Swamp	No
	Site 5	J33 23417 58285 (S50/51 4502 6537)	M	1,3,2	Swamp	No
	Site 6	J33 23418 58285 (S50/51 4503 6537)	M	1,3,2	Swamp	No
	Site 7	J33 23418 58287 (S50/51 4504 6539)	M	1,3,2	Swamp	No
Waitaha River	Ounatai Lagoon	133 23189 58028	M	7,1	Native bush	No
Wanganui River	Oneone River	134 23000 57931 (S63 4040 6158	M	1,7,2	Native bush/swamp	Yes

Catchment	Site location	Metric (NZMS 260) map reference†	Vegetation type*	Vegetation class*	Upstream catchment land use	Vegetation profile
Poerua River	Mainstem	134 23991 57921 (S63 4029 6147)	N	8	Native bush/pasture	No
Waitangitaona River	Spring-fed tributary	H34 22864 57821 (S63 3889 6040)	M	7,1,2	Pasture/native bush	Yes
	Mainstem Island	H34 22864 57821 (S63 3885 6039)	N	7	Pasture	No
Makawhio River	Papakeri Creek	G36 22391 57315 (S78 3364 5498)	?	?	Swamp	No
	Mainstem backwater	G36 22393 57317 (S78 3364 5498)	M	1,3	Bush/pasture	Yes
	Island drain	G36 22391 57323 (S78 3361 5505)	M	1,7	Native bush	Yes
Turnbull River	Collyer Creek, 8 sites					
	Site 1	F37 21819 56917	N	2,1	Native bush	No
	Site 2	F37 21819 56917	N	2,1	Native bush	No
	Site 3	F37 21818 56919	N	2,1	Native bush	No
	Site 4	F37 21817 56918	N	2,1	Native bush	No
	Site 5	F37 21817 56918	N	9,1	Native bush	No
	Site 6	F37 21816 56917	N	9,1	Native bush	No
	Site 7	F37 21816 56917	E	1	Native bush	No
	Site 8	F37 21816 56917	E	1	Native bush	No

† = NZMS 1 map reference is given in brackets where metric maps are not yet published.

*Vegetation types and classes:

N = native.
E = exotic.
M = mixed.
1 = long, lank exotic grasses (tall fescue, creeping jenny, etc.).
2 = flax.
3 = rushes.
4 = moss.
5 = emergent musk.
6 = willows.
7 = sedges (*Carex* spp.).
8 = tree ferns (Punga).
9 = *Hebe/Coprosma*
10 = raupo.
‡ = currently set aside for regeneration as a native vegetation reserve.
# = site damaged by diesel oil spill in 1990.

APPENDIX IV. Field data recorded from sites where inanga spawning or pre-spawning behaviour was observed.

Date	Site	Distance from salwater wedge (m)	Position°	Time spawning started (minutes after high water)	Time spawning finished (minutes after high water)	Days after new moon	Distance inland (km)	Activity‡ index
19.03.88	Ashley River tributary	3	B	?	?	1	2.5	3
22.01.88	Saltwater Creek	60	B	?	?	3	3.2	1
22.01.88	Benzie's Creek	100	B	15	45	1	2.5	4
19.03.88	Benzie's Creek	100	B	?	?	1	2.5	4
20.03.88	Kaiapoi River	100	B	?	?	2	3.5	2
17.04.88	Kaiapoi River tributary	120	B	?	?	0	3.5	2
27.02.90	Avon River	3400	A	40	60	2	10	2
09.02.89#	Heathcote River	1500	A	?	55	3	15	N/A
10.02.89#	Heathcote River	1500	A	0	90	4	15	N/A
11.02.89	Heathcote River	1500	A	60	?	5	15	3
11.03.89	Heathcote River	1500	A	60	105	3	14.5	3
12.03.89	Heathcote River	1500	A	65	?	4	14.5	2
19.04.91	Heathcote River	0	X	45	70	4	12	2
20.04.91	Heathcote River	0	X	?	?	5	12	1
10.04.89	Lake Ellesmere	N/A	A	50	95	4	2	2
12.04.89	Lake Ellesmere	N/A	A	?	?	6	2	2
28.03.90	Boat Creek, Rakaia River	N/A	A	40	90	1	3	3
28.03.90	Mathias Creek, Rakaia River	N/A	A	?	60	1	1.2	1
29.03.90	Boat Creek, Rakaia River	N/A	A	20	50	2	3	2
30.03.90	Oparawa River	?	?	?	?	3	1-2	?
10.03.89	Bakers Creek, Karamea River	?	A	75	?	2	3	3
11.03.89	Bakers Creek, Karamea River	?	A	?	105	3	3	3
12.03.89	Bakers Creek, Karamea River	?	A	17	?	4	3	3
13.03.89	Bakers Creek, Karamea River	?	A	6	?	5	2?	3
29.03.90	Granite Creek, Karamea River	?	A	?	?	2	3.5	4
29.03.90	Kongahu Creek, Karamea R.	?	A	?	120	2	3.5	3
10.02.89	Club Drain, Buller River	?	A	45	70	4	2	4
28.03.90#	Bradshaws Creek, Buller R.	?	A	?	30	1	5	N/A
29.03.90#	Bradshaws Creek, Buller R.	?	A	-60	0	2	5	N/A
30.03.90	Bradshaws Creek, Buller R.	?	A	70	100	3	5	4
28.02.90*	Cobden Island, Grey River	25-50	A	87	107	3	1.5	3
28.03.90	Cobden Island, Grey River	25-50	A	?	?	1	1.5	4
25.03.90	Cobden Island, Grey River	25-50	A	90	?	2	1.5	3
25.04.90	Cobden Island, Grey River	25-50	A	30	60	0	1.5	3
18.04.88	Mahinapua, Hokitika River	50	A	30	60	1	1.2-2.5	1-2

Date	Site	Distance from salwater wedge (m)	Position°	Time spawning started (minutes after high water)	Time spawning finished (minutes after high water)	Days after new moon	Distance inland (km)	Activity‡ index
09.02.89	Waitaha, Ounatia Lake	40	B	15	60	3	0.3	3
??.02.90	Oneone River, Wanganui R.	25-50	A	?	?	3	0.3	2
28.02.90$	Poerua River mainstem	50	A	17	77	3	0.3	2
10.02.89+	Waitangitaona River	300	A	27	90	4	0.7	2
28.03.90	Manakaiaua River	?	?	?	?	1	1.5	4
27.04.90	Manakaiaua River	?	?	?	?	1	1.5	2
26.03.90	Makawhio (Jacobs) River	70	A	75	?	-1	1.1	4
10.03.89‡	Turnbull River	556	B	13	38	2	2.5-3.2	4
11.03.89	Turnbull River	?	B	17	60	3	2.5-3.2	2

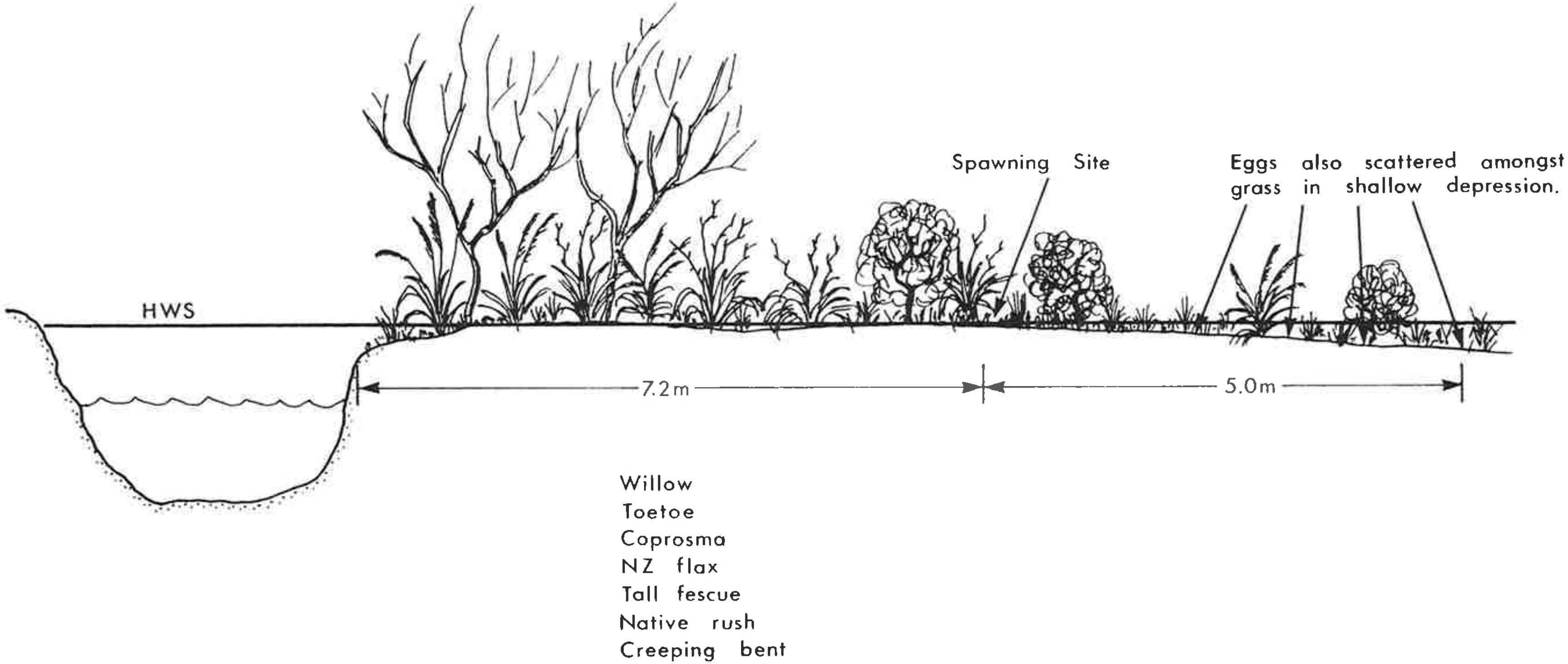
° = A is above saltwater wedge, B is below saltwater wedge, and X is at the termination of the wedge.

‡ = activity index, a subjective ranking for spawning activity:

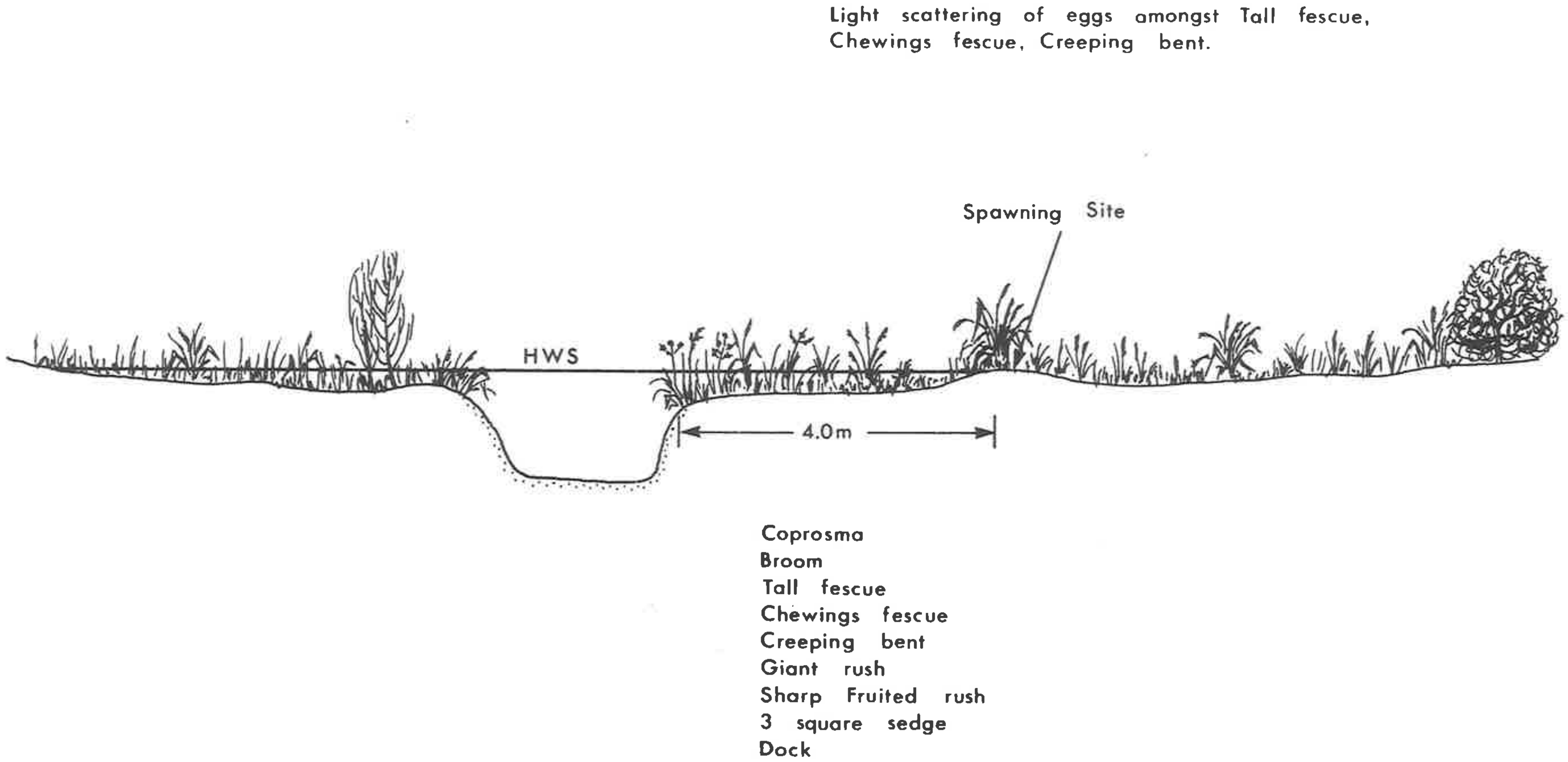
5 = heavy milt discolouration, large spawning shoals, 1000's of fish;
4 = milt discolouration, conspicuous shoals, 100's of fish;
3 = detectable milt, spawning conspicuous, audible 20 m, shoals of up to 100 fish;
2 = no milt, shoals of 50 fish, just audible;
1 = no milt, not audible, fewer than 50 fish seen.

? = data not recorded.
= pre-spawning behaviour only observed.
* = spawning terminated by falling tide, stranding unspawned fish.
$ = this site comprised a steep eroded bank, with fish spawning on punga logs.
+ = spawning at this site also took place on a full moon tide, two weeks before.
‡ = distance from the saltwater wedge to the eight spawning sites is a mean figure.

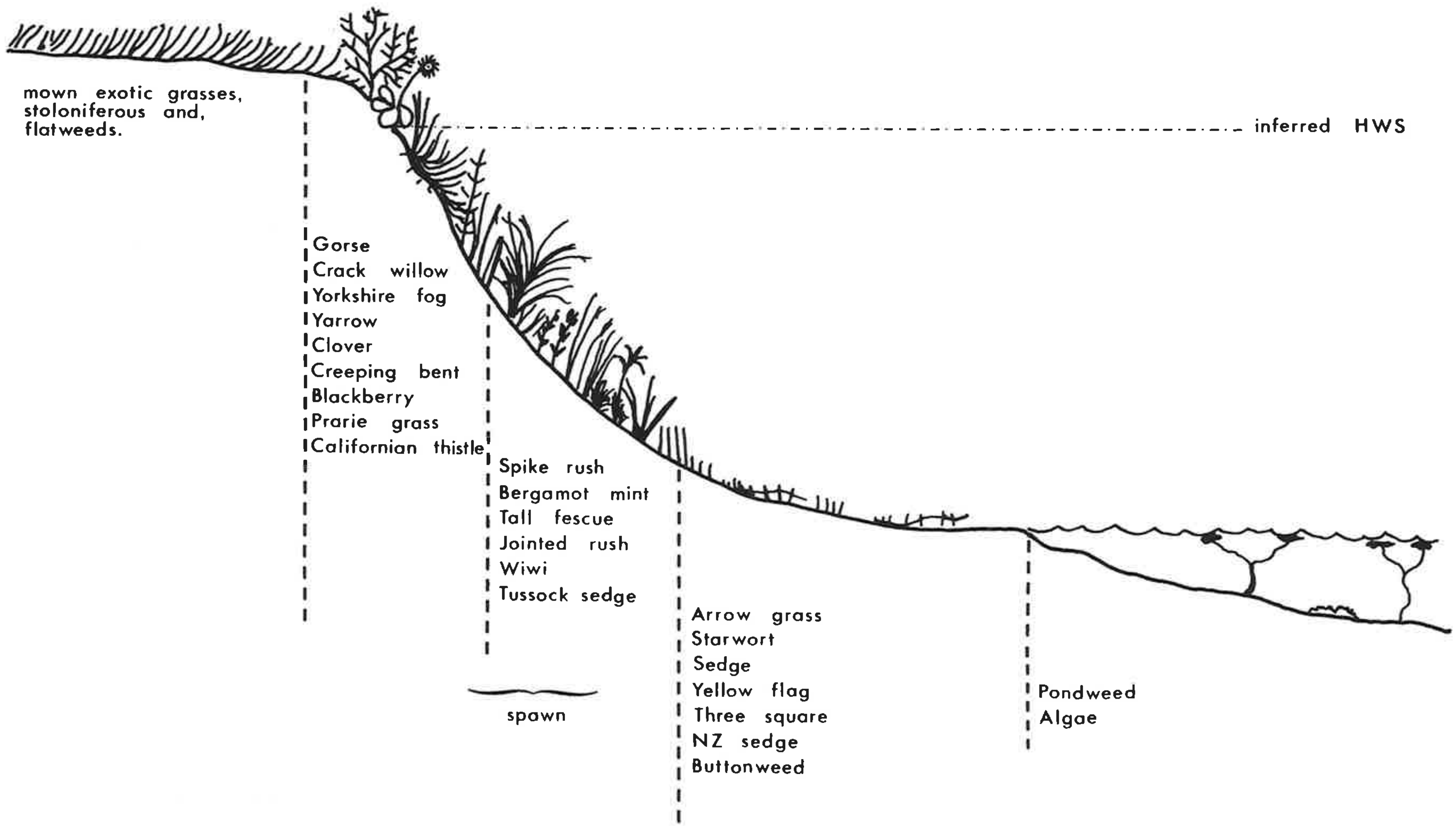
APPENDIX V. Vegetation profile at the inanga spawning site on Benzie's Creek, Ashley River catchment.



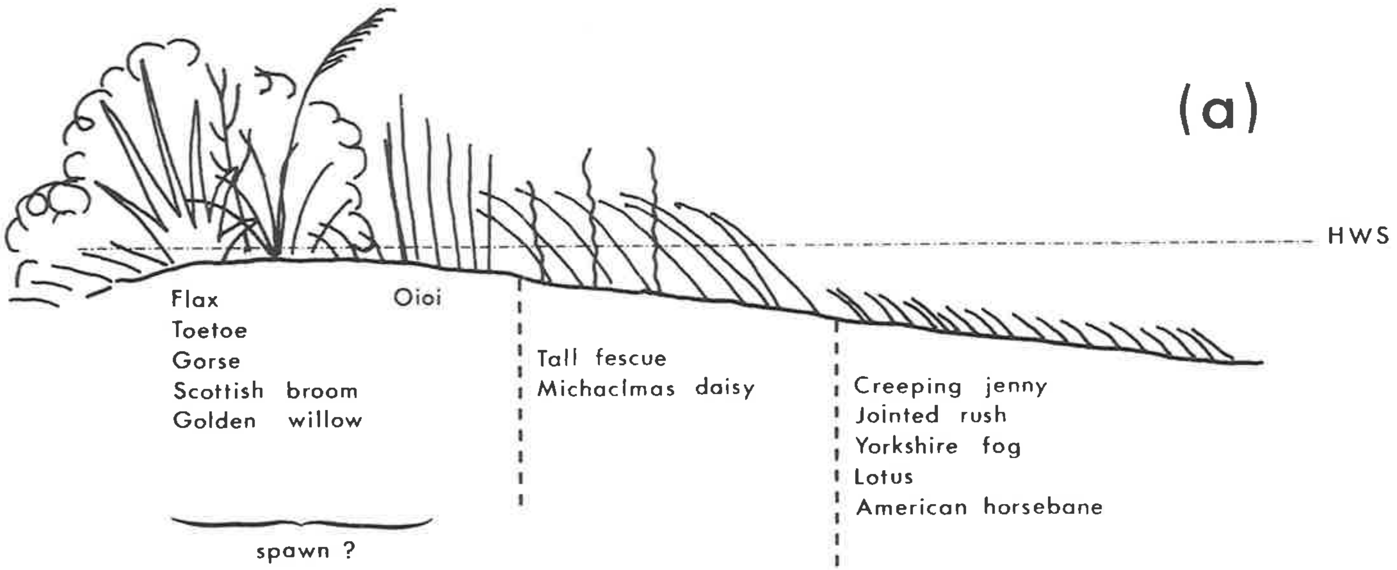
APPENDIX VI. Vegetation profile at the inanga spawning site on the unnamed Ashley River tributary.

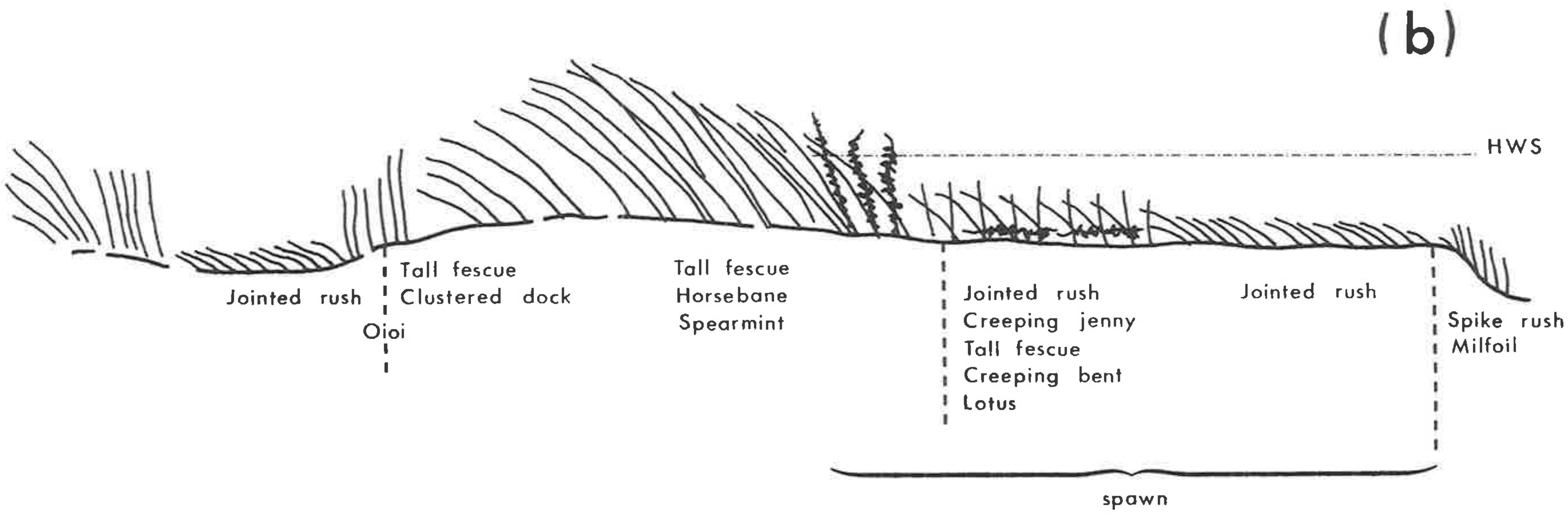


APPENDIX VII. Vegetation profile of the inanga spawning ground on the true right bank of the Avon River, near Avondale bridge.

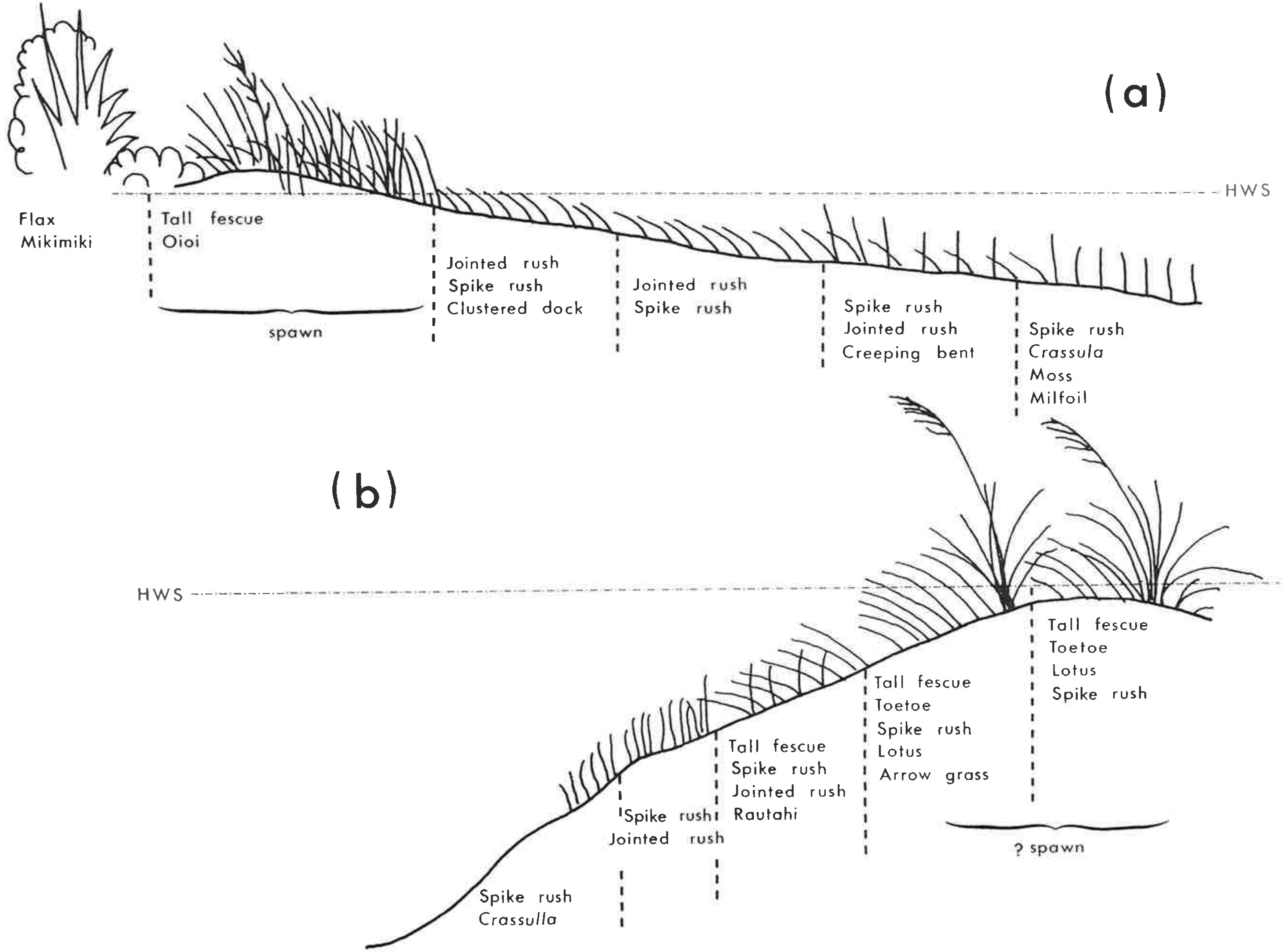


APPENDIX VIII. Vegetation profiles at the inanga spawning sites on Cobden Island, Grey River, (a) south site and (b) north site.

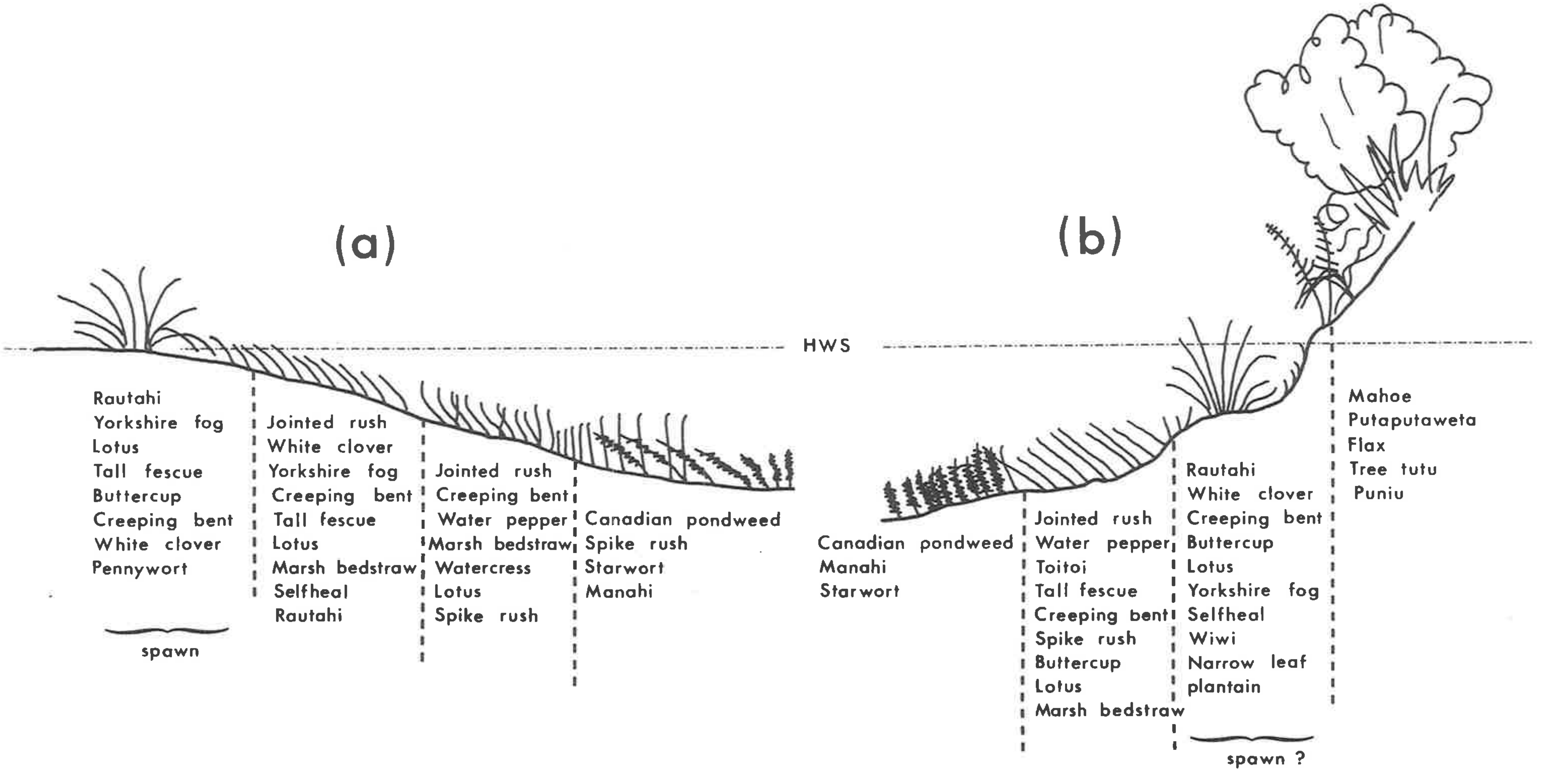




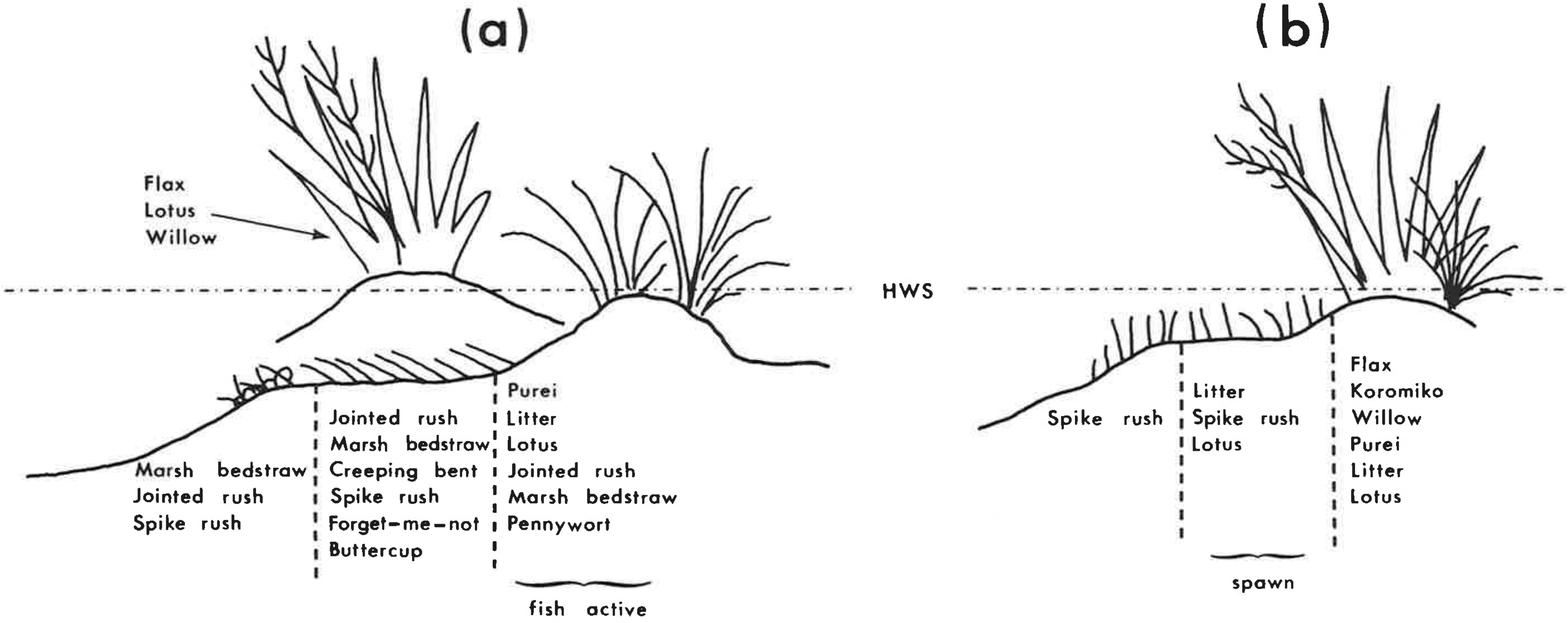
APPENDIX IX. Vegetation profiles at inanga spawning sites on (a) Mahinapua Creek, and (b) Wanganui (Oneone) River.



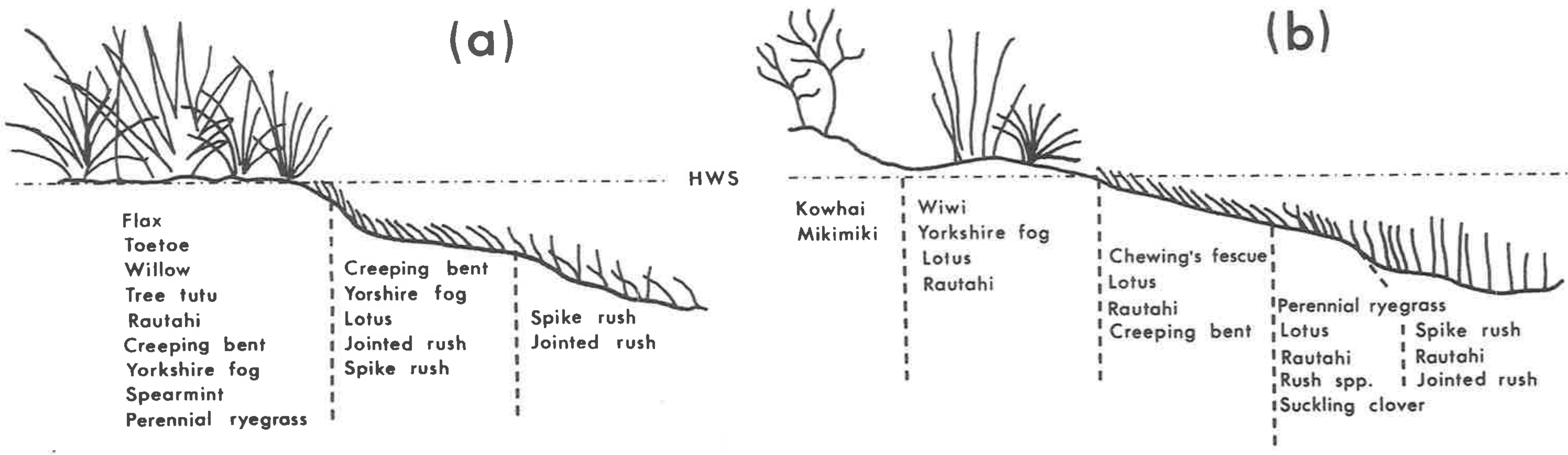
APPENDIX X. Vegetation profiles at two inanga spawning sites on the Waitangitaona River.



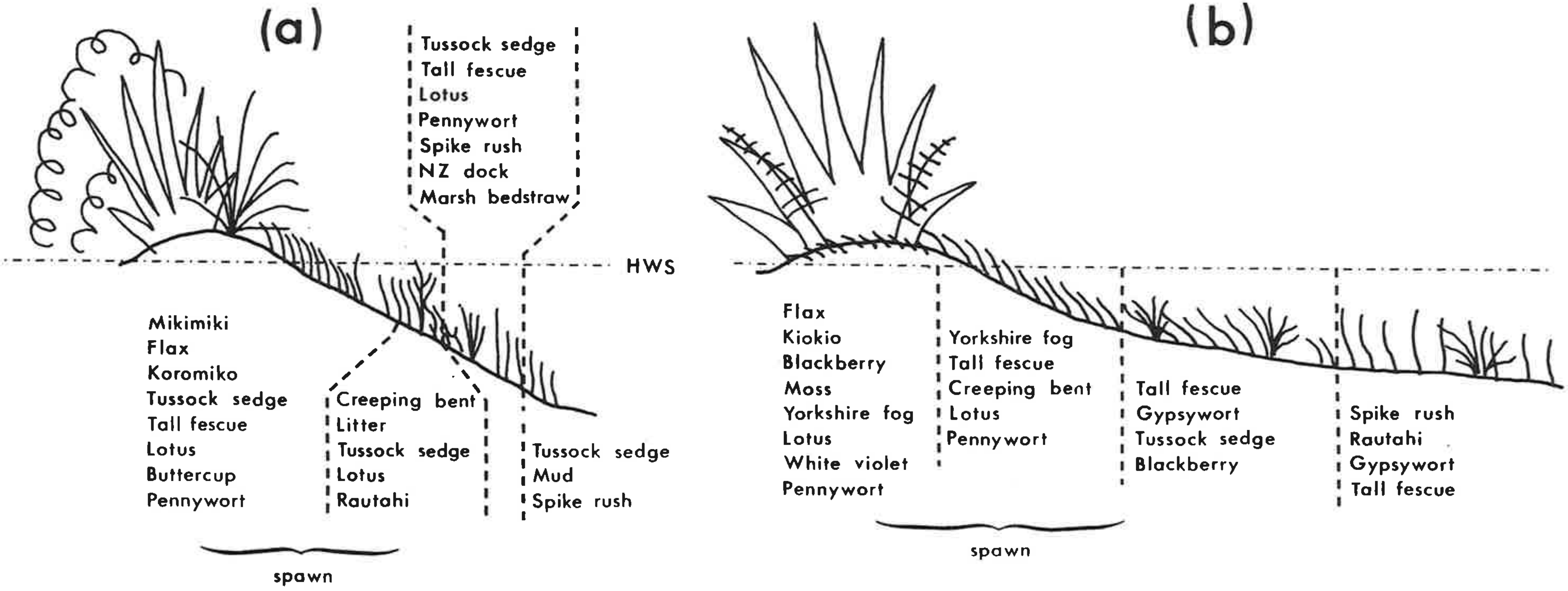
APPENDIX XI. Vegetation profiles at two inanga spawning sites on Sam Creek, Manakaiaua River catchment.



APPENDIX XII. Vegetation profiles at two inanga spawning sites on Jacobs Creek, Makawhio River catchment, (a) mainstem backwater and (b) north bank creek.



APPENDIX XIII. Vegetation profiles at two inanga spawning sites on the Turnbull River, (a) site 3 and (b) site 4.



APPENDIX XIV. Inanga spawning survey form.

INANGA SPAWNING SURVEY

Instructions on how to complete this form are provided on the back.

SITE LOCATION DATA			Number:
Survey date	Map sheet No. NZMS(260/1)	Easting:	Northing:
Surveyors' name:	Contact address:	Survey agency:	Catchment No. (if known)
Catchment name:		Surveyed bank length (m):	
Locality:			
Extent of survey:			
SURVEY SITE DATA			
Were eggs found or spawning observed? Eggs / Spawning / Both / Neither	Has spawning previously occurred at this location? (Yes / No / Unknown)	Is there a culvert or tidegate which impedes inanga passage at high water (Yes / No / Unknown)	Is the saltwater limit downstream of the site? (Yes / No / Unknown)
Time spawning first observed	Time spawning commenced (if known)	Time spawning ceased (if known)	Time of high water at site
Spawning was observed on the (New moon / Full moon / Unknown) spring tides	Approximate area of spawning site (m^2)	Distance (m) from spawning site to upstream limit of saltwater	Peak spawning activity index (1-6) 1, 2, 3, 4, 5, 6
LAND USE, TENURE, VEGETATION, AND IMPACTS			
Land Tenure Private / DOC / Leased / Other	Lot number and Deposited Plan No.	Name/Address of landowner:	
Predominant land use Urban / Wasteland / Reserve / Industrial / Recreational / Pastoral / Other	Spawning vegetation code numbers (key overleaf) — Grasses	Herbs	Native vegetation
Nature and extent of perceived threats to spawning			
SPAWNING SITE SKETCH			
Notes:			

Return to: M J Taylor, Freshwater Fisheries Centre, PO Box 8324, Riccarton, Christchurch