A guide to restoring inanga habitat

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Abstract

Richardson, J.; Taylor, M.J. (2002, reprinted with minor revisions 2004). A guide to restoring inanga habitat. ***NIWA Science and Technology Series No. 50.*** **31 p.**

The annual upstream migration of whitebait creates an important recreational and commercial fishery in New Zealand. The juveniles of five species of *Galaxias* and juvenile smelt (*Retropinna retropinna*) make up the whitebait catch, but in most rivers and streams inanga (*G. maculatus*) is the most abundant species. Inanga have a nationwide distribution, but many of their habitats have been affected by urban and rural development and no longer support inanga populations. This has contributed to a gradual decline in the size of the whitebait runs. This report provides information for locating, protecting, and restoring habitat for adult inanga in streams and for inanga spawning habitat in estuaries.

After migration into fresh water, inanga grow to maturity in low gradient and low altitude waterways. Providing upstream access is an important means of increasing habitat for adult inanga as they have little climbing ability. Consequently, poorly designed culverts and weirs can arrest their upstream migration. This guide illustrates examples of both good and bad structures. Toxicity tests have shown that inanga are relatively tolerant of low levels of pollution. However, ways to reduce common pollutants are given and adoption of these should gradually improve water quality. Not all streams provide suitable habitat for inanga because they feed in relatively slow flowing water. Pools, slow runs, or backwaters are their preferred habitats. Highest inanga numbers are also associated with areas that have cover such as overhanging vegetation or macrophtye beds. Photographs are used to demonstrate good inanga cover, as well as streams suitable and unsuitable for restoration projects.

Inanga spawn amongst riparian vegetation in estuarine areas, usually near the upper limit of the saltwater wedge associated with high tides. The same spawning sites are used year after year, and critical spawning areas can therefore be protected and improved. Methods for locating spawning sites, including equipment needed, when, where, and what to look for, are explained. Search strategies might include a high tide search for spawning fish or a low tide search for eggs. The advantages and disadvantages of both are listed. Many spawning sites require continuous management to ensure the vegetation remains suitable for egg development. Ways to achieve this and how to improve spawning habitat are both outlined.

Introduction

In spring, New Zealanders from all walks of life advance on river mouths to try their luck at catching the cultural and gastronomic icon locally known as whitebait. Although the catch includes the juveniles of smelt (*Retropinna retropinna*) and five species of *Galaxias*, in most rivers and streams, inanga (*G. maculatus*) is by far the most abundant species (McDowall 1984). Inanga have a diadromous life cycle that is typical of the whitebait species (Figure 1). Juvenile inanga migrate up stream in spring and it is this migration that whitebaiters target. Over the summer, inanga grow to maturity in freshwater habitats that include flowing waters, coastal lagoons, swamps, and lakes. In autumn, mature inanga migrate back down stream to spawn among riparian vegetation that is flooded by spring tides. Most adults die after spawning and few inanga live for more than one year. The eggs develop out of the water within the moist riparian vegetation and usually hatch soon after being resubmerged on the next series of spring tides. The larvae are then washed out to sea where they remain until the upstream migration the following spring.

The whitebait fishery has declined since the early 1900s (McDowall 1984). Overfishing, the introduction of exotic fish species, and habitat degradation and destruction have been advanced as probable causes. In response to concerns about the fishery, during the past four years NIWA has conducted interrelated studies on life cycle stages of inanga to develop management strategies to protect and enhance inanga populations. These studies build on earlier research on whitebait escapement (Mora 1992), spawning habitat (Mitchell & Eldon no date, Mitchell 1991, Taylor et al. 1992) and adult habitat (Sagar 1993).

In addition to our research, developments in global positioning system (GPS) and geographical information system (GIS) technologies have improved our ability to locate important sites and to combine information to facilitate better decision making. Changes in environmental legislation (e.g., the Resource Management Act) and statutory responsibilities (e.g., the Regional Council Act), together with the promotion of New Zealand's "clean green" image, have raised the public's awareness of their environment and sparked a desire to participate in conservation projects. Although the whitebait fishery may be in decline, some of the habitats used by inanga are ideal candidates for restoration and enhancement projects.

Our research has indicated that whitebaiters catch only a small proportion of the whitebait run in medium to large rivers (Mora 1992, Allibone et al. 1999), so further restrictions on the fishery are unlikely to have much impact on inanga populations. In contrast, studies of freshwater growth and egg development showed mortality during these stages was very high (Mitchell 1991, Richardson et al. 2000), so management strategies that improve inanga adult and spawning habitat and increase survival could substantially benefit the fishery. However, people need to know where to start, and this report provides methods for locating, protecting, and restoring stream and spawning habitats for inanga.

Knowing how to protect and improve adult and spawning habitats is only one part of the process associated with inanga stream restoration. After a site has been identified as being suitable for protection or restoration, registration, consultation, planning, implementation, and evaluation must also occur. Fostering the interest and enthusiasm of stakeholders is vital. The cooperation of landowners is required if livestock control, fencing, or riparian planting is required. Consultation with regional authorities might include obtaining funds from a regional council for purchasing plants. Maori groups can be strong advocates and appreciate being informed, even if they are not directly involved with land tenure.

Whole books have been devoted to the stream restoration process (e.g., Newbury & Gaboury 1993, Cowx & Welcomme 1998, de Waal et al. 1998, Ministry for the Environment 2001), but a more interactive publication is the CD-Rom available from Land & Water Australia (Rutherfurd et al. 1999). Although some aspects of the processes outlined in these documents would not apply in New Zealand or to inanga specifically, anyone considering a stream restoration project would find the information valuable. There is also a website that offers support and information to community groups interested in restoration activities in New Zealand (www.converge.org.nz).

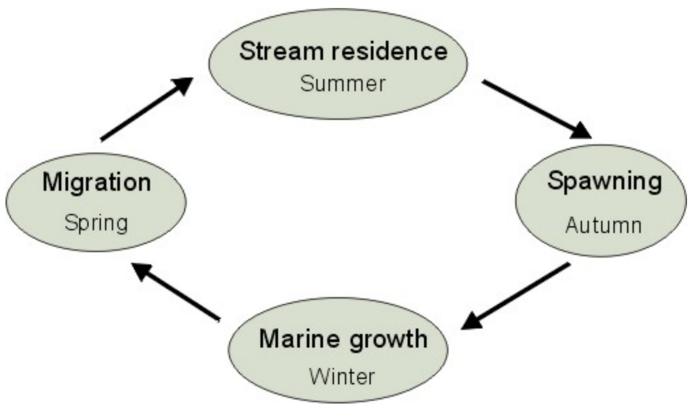


***Figure 1*: Inanga life cycle.**

Inanga stream habitat

After migrating inland from the sea, inanga spend the next 6 months in fresh water growing to maturity. Although both still and flowing waters are used by inanga, this document focuses on flowing water habitats. The topics covered include identification of critical parameters, such as the location and access to the waterway, and desirable features to protect and improve, such as cover and water quality. These are intended as a general guide because site-specific assessments and plans will usually be needed.

Location and physical attributes

The New Zealand freshwater fish database (NZFFD) is a site-specific database, maintained by NIWA, of fish presence/absence covering the whole of New Zealand. It contains over 18 000 records. Data extracted from the NZFFD show that inanga have a nationwide distribution, but they mainly live near the coast (Figure 2). Most sites where inanga are present are at altitudes of less than 20 m and less than 10 km inland (Figure 3). Although there is some leeway here, clearly, the closer the stream is to the coast, the better the chance inanga have of reaching the site. Waterways selected for protection or restoration should first meet this criterion.

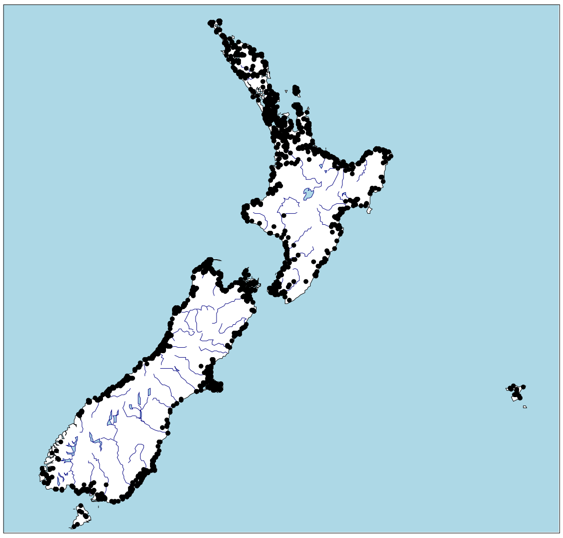


***Figure 2*: Distribution of inanga.**

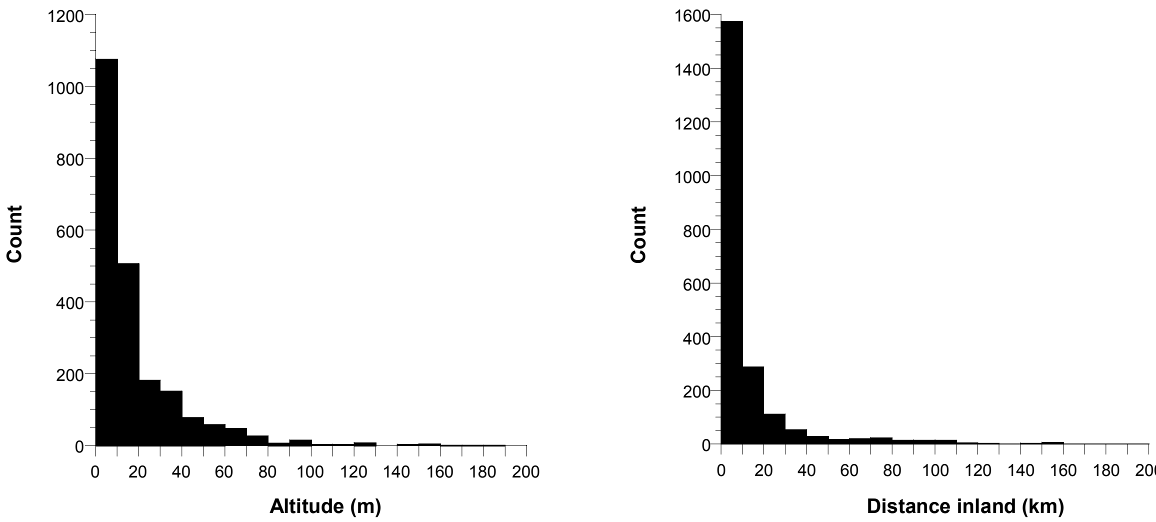


***Figure 3*: Elevation and distance inland of 2182 sites with inanga present from the NZFFD.**

The gradient and hence velocity of the waterway are also important considerations. Sagar (1993) found that mean velocities of streams inhabited by inanga varied between 0.1 and 0.6 m s^{-1}. Jowett (2002) observed that feeding inanga were located in pools or slow moving deep runs, and were either feeding where water currents concentrated food or were moving about near the surface of pools seeking food. The velocities used by feeding inanga were between 0.03 and 0.07 m s^{-1}. He also found that depth was less important than velocity for feeding, although depths greater than 0.3 m were optimal. Data from the NZFFD also show that inanga are found more often in streams with low velocity habitats (Figure 4) and potential restoration sites should therefore be slow flowing waterways or at least have abundant low velocity areas such as pools and slow runs. Although inanga occur more frequently in streams with fine substrate, such as mud or fine gravel (Sagar 1993; Figure 4), this is probably an artefact of the low elevation and low velocity of inanga streams rather than an actual substrate preference.

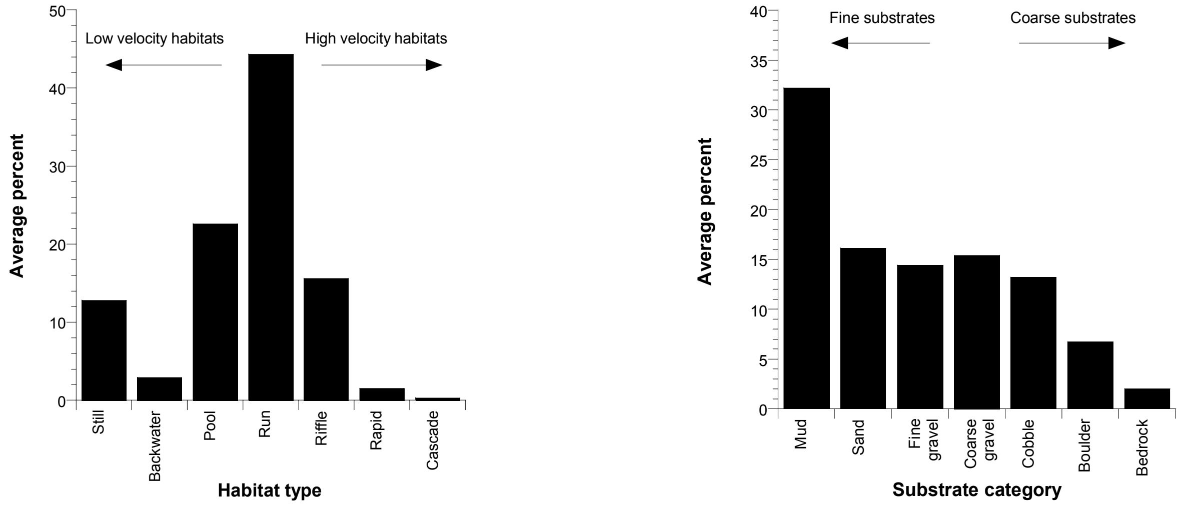


***Figure 4*: Habitat types and substrate categories from inanga sites in the NZFFD.**

Catchment land use is not a critical factor; inanga occur equally in waterways draining pasture or native forest (Figure 5). They are even found in urban areas providing water quality has not been degraded. Stream size is also not important as long as there is a permanent year-round flow; inanga are found in streams as small as 1 m wide up to large waterways (Figure 5). However, it is probably impractical to attempt a restoration project on a large waterway unless a catchment-wide approach can be undertaken.

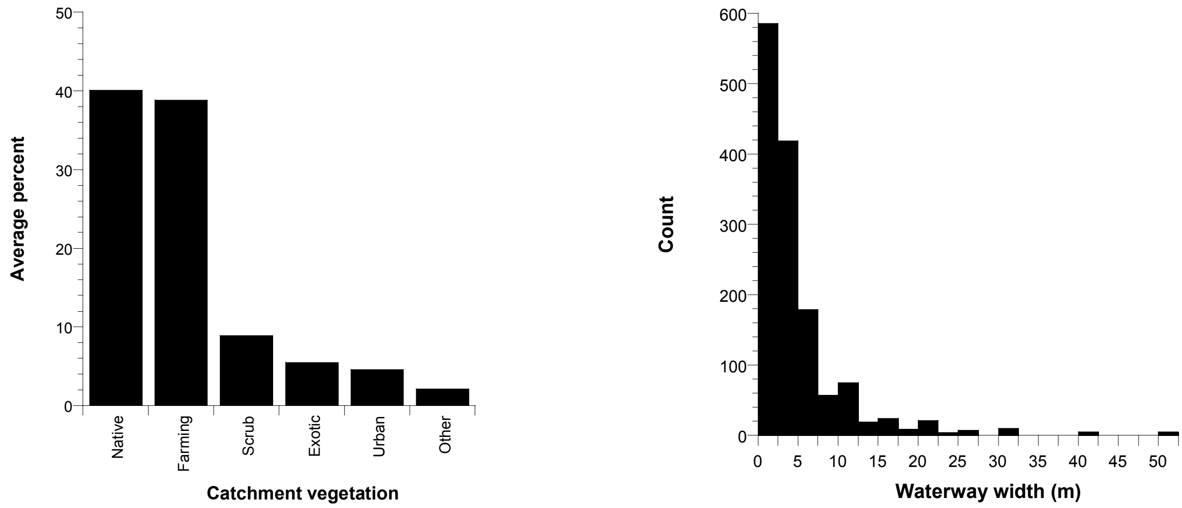


***Figure 5*: Catchment vegetation and waterway width from inanga sites in the NZFFD.**

Access

After location, access is the most important consideration when looking for an appropriate stream to improve for inanga. Inanga have little climbing or jumping ability, but are good swimmers for their size; both their burst and sustained swimming speeds are equivalent to those of the salmonids (Boubée et al. 1999). Obviously, the presence of natural features, such as waterfalls or swift rapids, will sometimes mean that inanga cannot penetrate further upstream. However, man-made features, particularly floodgates and culverts, may also cause passage problems for inanga and hence reduce naturally available habitat.

Floodgates can pose significant migration problems for inanga for two reasons. First, they are designed to exclude the pulse of tidal water that naturally occurs in lowland coastal waterways and thus are positioned within the tidal zone. Usually, when the tide is flooding, the floodgate is closed to prevent saltwater intrusion (Figure 6). This restricts fish passage to the ebbing tide period and means that fish must migrate against the water current rather than with it. Therefore, not only is passage difficult for inanga, but also the location of the floodgate can potentially prohibit access to substantial areas of lowland habitat.

***Figure 6*: Examples of closed and open floodgates.**

Poorly designed culverts can also restrict inanga access to upstream habitat. Figure 7 shows two culverts that inanga, and indeed many other native species, could not surmount. The flows through the culverts in the ford on the left are too swift for inanga to negotiate. In addition, the small cascade below the ford means that inanga could not reach the culverts. The figure on the right is an extreme example of a perched culvert where the downstream end of the culvert is perched above the water level. No fish species could negotiate this culvert and it effectively blocks access to all upstream habitats.

Examples of culverts that will allow inanga access up stream are shown in Figure 8. Their good features are that the base of the culvert barrel has been sunk below the streambed, thus preventing perching or steep drops at the downstream face. The slope of these culverts is also such that flows through them are not too swift for inanga to swim through. The culvert on the left is wide enough so that a natural wetted margin is present on the left hand side, and there are a few large rocks present to provide resting areas.

Mitchell (1989) measured the swimming speed of inanga in a flume, and showed that the sustained swimming speed (speed able to be maintained for more than 20 min) was only 0.2 m s^{-1}. NIWA carried out further experiments, and developed equations to calculate burst and sustained swimming speeds based on inanga size (Boubée et al. 1999). These show that velocities for sustained swimming are low, particularly for juvenile inanga (Figure 9).

Figure 7: **Examples of culverts that prevent upstream passage by inanga.**

Figure 8: **Examples of culverts that allow inanga access to upstream habitats.**

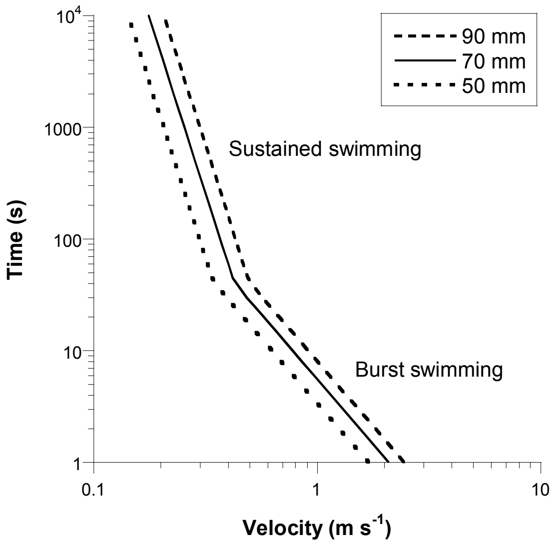


Figure 9: **Sustained and burst swimming speeds for inanga 50–90 mm in length. Values are calculated from the equations of Boubée et al. (1999).**

Other man-made features such as weirs and dams can also prevent access by inanga. Recent experiments have shown that adult inanga are capable of passing over weirs with up to a 15 cm vertical drop by burst swimming (Figure 10). Fish that attempted to jump the weir were unsuccessful, and although the shape of the weir was not a significant factor, the flow of water over the weir and the height of the vertical drop were (Baker & Allibone 2002). However, most whitebait were incapable of passing over even a 5 cm high weir.

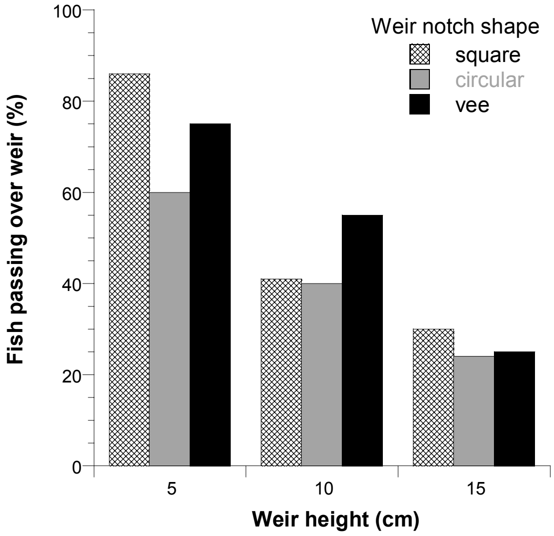


Figure 10: **Relationship between weir height and shape and the percentage of adult inanga able to pass the weir.**

Ramps may be simple way of ensuring successful inanga passage past obstacles in streams. Recent studies investigated the effects of ramp slope and surface type on the passage of adult and juvenile inanga (Baker & Boubée 2003), and showed a high percentage of inanga were able to negotiate ramps set at a 15° slope so long as some surface material was provided (Figure 11). At a 30° slope, fewer fish were able to climb the ramp, and the best surface appeared to be stripdrain, a plastic material that has small rounded cones jutting up from a flat surface. At a 45° slope, no juvenile inanga were able to negotiate the ramps, and for adults, passage was only successful when stripdrain was used. However, gravel was also a relatively successful surface, and is cheap and easy to obtain. It may also be less likely to clog with debris than rougher surfaces. Regardless of the surface type, having the ramp tilted so that one side always has a wetted margin is essential for ensuring inanga passage because it creates low water velocities on the shallow edge.

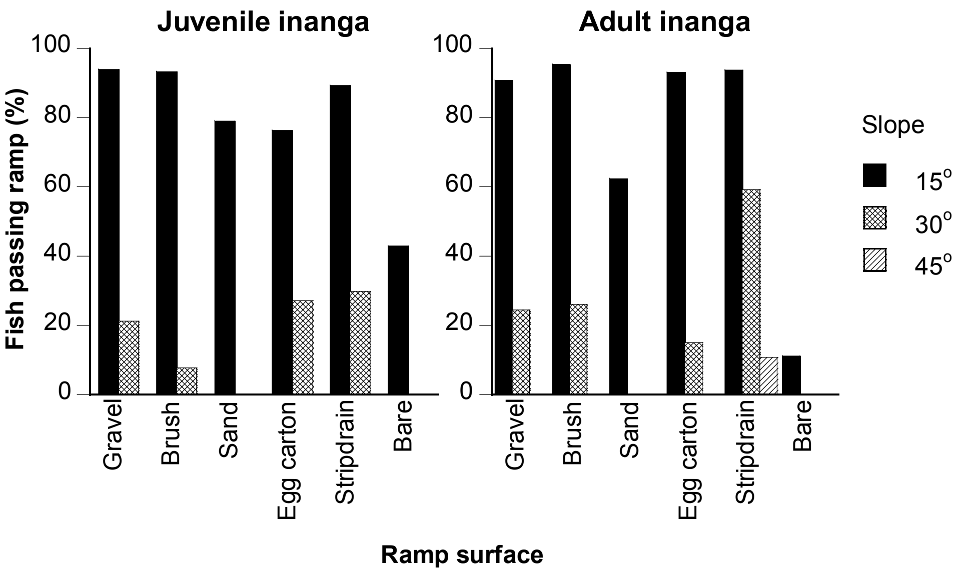


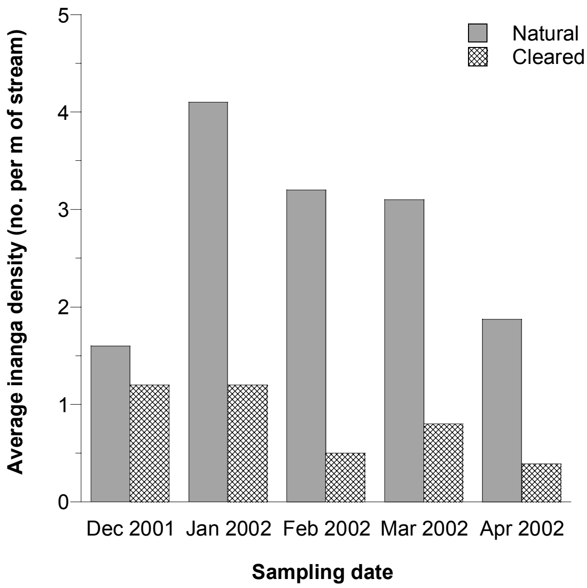
Figure 11: **Relationship between ramp slope, surface material and the percentage of inanga able to pass the ramp.**

Cover

Cover (shelter) is an important, almost essential, feature of good inanga streams that, fortunately, can be protected, restored, or improved relatively easily. In small waterways, cover is usually provided by riparian vegetation that overhangs the edges of the stream. This does not need to be especially tall or native vegetation; inanga thrive in streams flowing through grazed pastureland provided the stream banks have not been completely denuded and trampled by livestock or the vegetation removed by spraying or mechanical means. Slightly overhanging banks, especially if they are covered by vegetation, also make good cover for inanga. Deeply undercut banks are more suitable for other galaxiid species, such as banded (*G. fasciatus*) or giant (*G. argenteus*) kokopu, and eels (*Anguilla* spp.), and are not usually occupied by inanga.

The importance of cover was emphasised in a recent experiment on a small stream known to provide good cover for inanga (Richardson 2002). In November 2001, all the cover was removed from five reaches on this stream by clipping off all the bank vegetation, removing all the woody debris, and cutting back any overhanging banks. Five adjacent reaches were left in a natural state. Over the next five months, the inanga population in both cleared and natural reaches was assessed by electric fishing. Effects on the inanga population were pronounced, with up to 4 times more inanga occurring in the natural reaches compared to the cleared sections (Figure 12). Woody debris was particularly important in this stream because it caused the water to back up and create the deep, slow flowing pools that inanga prefer. Without the wood, the cleared sections becoming shallower, wider, swifter and more uniform than the untouched reaches, and therefore poorer inanga habitat (Figure 13). Allowing woody debris to accumulate in small streams could be as important for inanga as allowing the bank vegetation to overhang the stream.

***Figure 12*: Inanga density from natural and cleared reaches of the study stream, December 2001 – April 2002.**



In larger streams, beds of submerged aquatic plants also provide cover for inanga. Generally, inanga live near the edges of the weed beds, and require clear patches of water for feeding. Thus, streams that are choked with vegetation are not good habitat for inanga. Larger waterways with bare gravel banks are also not good inanga habitat, even if large rocks and stones are present. Inanga rarely use substrate as cover. Figures 14–23 show examples of suitable and unsuitable streams for inanga.

***Figure 13*: Natural (above) and cleared (right) sections of the study stream. Note how the small logs in the natural section create pool habitat and that the overhanging grasses provide bank-side cover. In the cleared section there are no distinct habitat features and the result is poor inanga habitat.**

***Figure 14*: Suitable — the flow of water in the foreground of this picture is probably a little too swift for inanga. However, the depths and velocities above the submerged pipe are appropriate, and the backside vegetation, although short, provides suitable cover.**

***Figure 15*: Suitable — a similar situation as in Figure 11 but overall the cover is better. Inanga would find suitable habitat along the edges where the velocity is lower and where there is good cover.**

Figure 16: **Suitable — although this stream is small, water depth and velocity are ideal for inanga. There is also plentiful riparian cover.**

Figure 17: **Suitable — water depth and velocity are excellent for inanga in this stream. The slightly undercut and overgrown bank on the right provides ideal cover, as do the emergent plants on the left bank.**

Figure 18: **Suitable — the macrophyte beds in this larger stream provide good cover for inanga, as does the vegetation along the banks. Depth and velocity are also about right, and there are clear patches among the weed beds for inanga to use as feeding stations.**

Figure 19: **Unsuitable — inanga require clear patches of water for feeding. An overgrown stream like this would not provide suitable habitat unless the weed growth could be controlled.**

Figure 20: **Unsuitable — steep, gravel-bedded rivers generally make poor inanga habitat because their high bed load causes a wide, open channel to form. Over time, the river shifts from side to side within the channel, so riparian vegetation has no chance to become established. Although some native species prefer this type of habitat, inanga are not among them. These types of rivers are impractical for restoration unless the amount of sediment entering the river can be reduced throughout the catchment.**

Figure 21: **Unsuitable — this stream is a smaller example of Figure 17. The stream has a high bed load of small substrate particles and hence flows in a wide channel where inanga cover cannot develop. The water is also too shallow. It would probably not be a good candidate for restoration.**

Figure 22: **Unsuitable — although there are areas with suitable depth and velocity in this stream, a lack of appropriate cover means that inanga will not live here. This stream may be a good candidate for restoration, but it would need closer inspection.**

Figure 23: **Unsuitable — this stream is obviously at an ideal altitude and inland distance for inanga, but, once again, there is no cover and inanga would not be abundant here. The stream is not particularly steep and bank stabilisation and planting would create a good environment for inanga.**

Water quality

Few lowland waterways remain in pristine condition, but toxicity experiments have shown that inanga are intermediate in their tolerance of pollutants compared to other native fish species. Common smelt (*Retropinna retropinna*) are generally more sensitive whereas eels (*Anguilla* spp.) are highly tolerant of pollutants. If a potential site already contains smelt, then water quality is probably suitable for inanga as well. If the site contains only eels, then some parameters may need to be improved. The toxicity of some pollutants is influenced by other parameters, e.g., the toxicity of ammonia increases as temperature and pH increase (Emerson et al. 1975). In addition, the effects of exposure to multiple contaminants can be greater than the sum of effects from individual exposures (Power 1997). Waterways that meet ANZECC (2000) water quality guidelines will be suitable for inanga and achievement of these guidelines should be a goal of any enhancement activity.

Water temperature

Inanga can tolerate water temperatures over 30 ˚C for very short periods, but their preferred temperature is about 20 ˚C regardless of the life stage (Boubée et al. 1991). Juvenile inanga were shown to avoid temperatures over 22–23 ˚C (Richardson et al. 1993) and to cease migration if temperature exceeded 27 ˚C (Stancliff et al. 1989). Thus, high temperatures can affect survival and upstream migration of inanga, although most migration occurs in spring when temperatures are not usually critical. Ideally, average summer temperature should be about 20 ˚C.

pH

Many lowland waterways inhabited by inanga contain extensive beds of submerged macrophytes that can cause major diurnal shifts in pH and dissolved oxygen (Wilcock et al. 1998). For example, maximum pH levels over 8 are not uncommon in lowland streams throughout the Waikato region (Wilson 1999). However, short-term experiments in a pH gradient tank showed that inanga are highly tolerant of high pH, preferring levels of about 9.5 and showing complete avoidance only at pH 10.5 (West et al. 1997). Thus, pH levels typically encountered in many lowland streams are unlikely to be detrimental to inanga.

In the same gradient tank, most inanga avoided pH levels of less than about 7 (West et al. 1997). This implies that naturally acid streams, such as those draining peat swamps, may be avoided by inanga, as pH in such habitats can be as low as 4 (Hicks & Barrier 1996). However, there is little that can practically be done to manage or change pH on a permanent basis. Most lowland streams draining pastoral land or scrub have pH between 7 and 10 and are suitable for inanga.

Ammonia

Ammonia generally enters waterways directly from livestock wastes or indirectly via poorly treated wastewater discharge from sewage treatment plants and industrial sources. Routine water quality monitoring of lowland streams draining pastoral land in New Zealand has shown that ammonia concentrations often exceed 0.4 mg NH_3 L^{-1} (R.J. Wilcock, NIWA, pers. comm.) and may be as high as 5 mg NH_3 L^{-1} (Hickey & Vickers 1994). Dairy-shed effluent ponds, particularly, can represent a significant toxic risk to fish populations, especially where multiple discharges occur. For example, surveys of 20 dairy-shed effluent ponds in the Auckland region showed that effluent ammonia frequently exceeded 360 mg NH_3 L^{-1} (Hickey & Vickers 1994).

Laboratory experiments showed that over a 96-hour period, 50% of inanga died at about 1.5 mg NH_3 L^{-1} (at pH 7.5 and 15 °C) (Richardson 1997). Overall, inanga were relatively tolerant of ammonia; of the eight native species tested, only eels were more tolerant than inanga. However, avoidance experiments showed that inanga had a poor ability to detect and avoid highly toxic concentrations of ammonia and were strongly attracted to levels equivalent to the 96-hour lethal concentration (Richardson et al. 2001). This lack of an appropriate response to ammonia pollution by inanga might result in mortality, particularly if highly toxic ammonia levels occur, even for a short time. As the toxicity of ammonia increases as pH and temperature increase, the potential for high levels to occur increases in summer when inanga are present in fresh water as aquatic plant growth and water temperatures are also high at that time. However, common bully (*Gobiomorphus cotidianus*), smelt, and shrimp (*Paratya curvirostris*) are considerably less tolerant of ammonia than inanga, and thus any waterway that contains these species would also be safe for inanga. Ensuring that animal wastes do not get flushed directly into waterways or that appropriate wastewater treatment is occurring can reduce ammonia pollution.

Dissolved oxygen

Laboratory experiments showed that inanga could survive 3 mg L^{-1} dissolved oxygen for at least 48 hours, the maximum exposure time used during the experiments (Dean & Richardson 1999). At 1 mg L^{-1} dissolved oxygen over the same time period, there was 100 % mortality of juvenile inanga, but only 38% of adults died.

In lowland streams with extensive macrophyte beds, diurnal minimum dissolved oxygen levels may fall as low as 3.5–4.5 mg L^{-1} during summer (Wilcock et al. 1998). However, unless there is a prolonged period (over 48 hours) at such low levels, dissolved oxygen levels occurring in most lowland waterways are unlikely to be problematical for inanga.

Suspended sediment

Although some whitebait species, particularly banded kokopu, are sensitive to suspended sediment, inanga are relatively tolerant of moderately high levels; laboratory experiments showed that migrating inanga did not show 50% avoidance until suspended sediment levels exceeded 400 nephelometric turbidity units (NTU) (Boubée et al. 1997), and that feeding was not significantly reduced below 600 NTU (Rowe & Dean 1998). Although lowland waterways are likely to be turbid, because their catchments are often highly modified, moderate levels of suspended sediment are unlikely to directly affect inanga.

However, high sediment levels may indirectly affect inanga by reducing their food supply. Quinn et al. (1992) found that clay discharges that increased turbidity from 7 to 154 NTU above background levels in clear Westland streams caused reductions of 9–45% in benthic invertebrate abundance compared to upstream sites. Dunning (1998) also showed that high sediment levels caused a reduction in invertebrate density and diversity in four North Island pine forest and pasture streams. Thus, increases in sediment levels may reduce food availability for inanga.

Other pollutants

In addition to the pollutants described above, a number of others are present in New Zealand waters, largely from primary industries and through point discharges. For example, mining, geothermal development, and stormwater drains can all contribute heavy metal pollution to waterways, whereas pesticides are often associated with agricultural development. The pulp and paper and timber industries use chemicals including metals, pentachlorophenol, and chlorinated organics. There has been some toxicity testing with heavy metals, phenol, and detergent (Hickey 2000), but generally, the toxicity of many of these pollutants to native freshwater fish is unknown. Although most discharges in New Zealand probably meet water quality guidelines, streams that flow through industrialised areas are likely to be less suitable for enhancement than those in a less developed setting simply because of the potential for other pollutants to be present.

Inanga stream management and enhancement

Although there are numerous books describing rehabilitation techniques, most of the techniques apply to swiftly flowing rivers and often involve creating pool/riffle sequences using boulders or logs or stabilising banks. Stream habitat modifications and restorations have been carried out in the United States for the past 100 years and a review by Beschta et al. (1994) concluded that, of the few major enhancement projects that had been monitored, structural approaches to improving fish habitat had not attained desired goals. They recommended that any proposed restoration work should consider that:

- the elimination of land-use activities that cause adverse impacts to riparian and aquatic ecosystems is of highest priority, if restoration is to be accomplished;
- bad land-use practices cannot be mitigated by structural additions to or modifications of the stream channel;
- ecological recovery and improvement requires time.

Depending on the stream, options for management and restoration may range from relatively simple activities, such as ensuring inanga can reach suitable habitat that has been made inaccessible for whatever reason, to a complete rehabilitation of the catchment. The shape and characteristics of a stream (the morphology) will dictate whether it can, or ever will, be suitable for inanga, and this should be assessed before deciding to proceed. Some of the more important morphological characteristics are the habitat types present (e.g., pool/run/riffle sequences), braiding pattern, sinuosity, width to depth ratio, and channel and bank shape. To a large extent, natural processes control morphology and our ability to change stream morphology is limited by these processes. The major determinants of stream morphology are:

- magnitude and frequency of flood flows,
- bed material (substrate and wood),
- bank material,
- stream gradient,
- amount of sediment transported.

An important feature of inanga streams is the way that velocity increases as the stream flow increases. When the flow in a stream increases, the water level rises and the velocity increases. Meanders are particularly effective in restricting flow. In meandering rivers, water levels rise during high flows and there is often very little increase in water velocity. When the river level rises above bank levels, water spills out onto the flood plain where well established vegetation can prevent excessive erosion. Meanders, flood plain vegetation, and riparian vegetation all play an important role in reducing water velocities at high flows and thus reducing erosion and scour.

The amount of sediment transported by a river also influences the habitat structure of a river. High sediment loads tend to reduce stream depths and create a shallow stream flowing in a wide gravel flood channel. Any pools formed in such an environment usually occur only where the stream impinges on strong banks, such as those formed by willow trees or bedrock.

As described earlier, inanga streams typically contain areas with low water velocity and cover. This tends to preclude unstable gravel-bed streams with high sediment loads (as shown in Figures 20–21) and to favour stable streams with riparian vegetation, woody debris, or macrophytes. Suitable habitat can be found either in low gradient meandering streams with mainly run habitat or in steeper streams with pool/riffle structures. The catchment conditions that promote good inanga habitat are low sediment transport rates and flood flows that are commensurate with the stream gradient, strength of the banks, and size of substrate. In low gradient streams, allow or assist natural meander patterns to develop. This will create pools and flow concentrations where inanga can live and feed.

Access is an important consideration. Designs for floodgates that protect land during flood events while still allowing fish passage are available, and should be considered if floodgates limit access to suitable habitat. Retrofitting a floodgate would require expert advice. NIWA has developed a computer program that uses fish swimming speed and culvert water velocity to calculate the maximum distances fish can travel. This program can be used to assess the ability of inanga and other native species to negotiate culverts and to design culverts that ensure inanga passage (Boubée et al. 1999). It is also sometimes possible to retrofit culverts to allow passage for inanga (Boubée et al. 1999). Although the culvert shown on the right in Figure 7 would have to be taken out and replaced to allow fish passage, the culvert on the left might be made passable by improving access at the downstream end and fitting baffles inside to reduce velocities.

The presence of good riparian vegetation, woody debris, or macrophytes will provide cover for inanga and meanders, coarse substrate, and large wood will create pool habitat. An important step toward restoring riparian vegetation on pastoral streams is to restrict livestock access to stream banks. Pest species, such as goats or possums, may also need to be controlled or eliminated. Even without artificial planting, some of the streams shown as being unsuitable would eventually regain their riparian vegetation, although landscaping the banks will obviously speed the process. In urban situations, stream banks should not be mown right to the water's edge, but a strip of longer grass left to overhang the water. Where excessive aquatic weed growth is a problem, mechanical clearing or spraying should take place in late autumn or winter after inanga have moved back to the estuaries to spawn.

As shown in Figures 13–18, plants that create suitable inanga cover include pastoral grasses, toetoe, flax, ferns, and watercress. Plant species that overgrow waterways, such as *Glyceria*, should be avoided because streams choked with vegetation are not good inanga habitat (Figure 19). Blackberry and gorse are also not particularly suitable plants because in small waterways they can eventually choke the entire stream and the undergrowth becomes quite sparse. In some areas, blackberry loses its leaves over winter and would not provide cover for inanga, although generally there are few inanga in fresh water over the winter. If blackberry or gorse invade the riparian vegetation, then controlled grazing or spraying might be needed to keep them under control. However, gorse can provide nurseries for native vegetation rehabilitation over several decades.

The most effective method of reducing water temperatures is by stream shading, but generally shade trees will need to be fenced as livestock tend to congregate under them in sunny weather, increasing the risk of bank trampling and collapse and faecal contamination. Although large trees do not provide cover for inanga, riparian vegetation can be planted in small streams in farmed areas to decrease summer water temperatures. Rutherford et al. (1997) showed that moderate shade levels (about 70%) might be sufficient to restore small pastoral stream temperatures to 20 ˚C in temperate climates. This is less than shade levels along small native forest streams, which typically reach 90–95%. In wide waterways (over about 10 m), riparian vegetation develops a channel gap, and thus has less influence on water temperature: it may be difficult to reduce water temperatures in wider streams.

There are several ways to reduce the sediment supply to streams. Roads and tracks should be sited and constructed so that erosion and run-off are minimal both during and after construction. During in-catchment activities such as harvesting forests, appropriate codes of practice should be adhered to. Where livestock have direct access to streams, banks can collapse and riparian vegetation can be destroyed. In addition, faecal material from livestock can reduce water quality and, in particular, increase ammonia. Restricting livestock access improves water quality and restores the riparian vegetation. Riparian vegetation not only provides shade that can reduce stream water temperatures and provide cover for inanga, it can also act as a buffer between developed land and the stream, absorbing sediment and excess nutrients (Quinn et al. 1993).

Generally each potential inanga site will need to be assessed individually before deciding whether to undertake any protection, restoration, or enhancement activities. Location and stream morphology will dictate your decision, but having the support of the other stakeholders is also critical. Remember that "good things take time" and a restoration project can be a lengthy process.

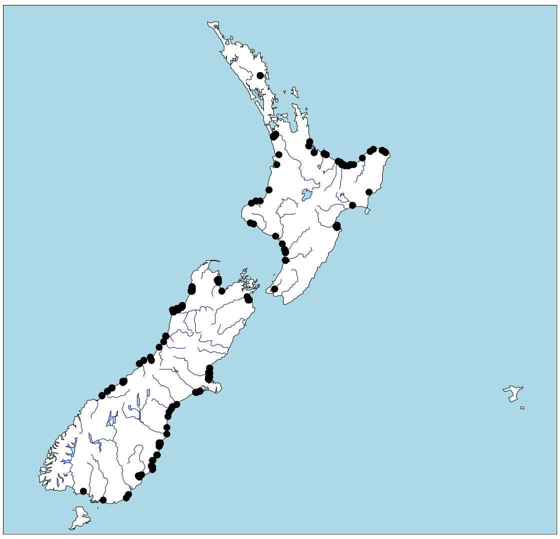
Inanga spawning habitat

After 6 months or so in fresh water, mature inanga migrate down stream in large schools to spawn in estuarine areas (see Figure 1). Inanga eggs develop above normal river levels amongst vegetation that is flooded by spring tides. This layer of moist overlying vegetation ensures the high humidity and moderate temperatures necessary for egg development. Most spawning takes place during late summer and autumn, but some occurs at other times; whitebait are found at river mouths during all times of year, but are most numerous between August and November.

In response to concerns about the decline of the whitebait fishery, the Department of Conservation (DOC) commissioned survey work in the late 1980s to locate inanga spawning sites and to identify the extent to which they were endangered (Taylor et al. 1992) This led to the identification and protection of many major spawning sites throughout New Zealand (Figure 24). However, not all sites have been located, and threats have not disappeared. For example, trampling by livestock and desiccation of eggs are threats along grazed river margins, whereas the mowing of grassed suburban riverbanks can compromise egg survival. Silt deposition during flood events and pollution have been implicated in the death of inanga eggs (Taylor et al. 1992), and eggs deposited on spawning sites below hydro-electric dams have completely disappeared after large releases of water (P. Ravenscroft, DOC, pers. comm.).

Successive inanga generations often use the same spawning sites year after year (Benzie 1968, Mitchell 1991), and this allows these ecologically sensitive areas to be identified, improved and protected. Methods for these activities are presented in the next section of the document.

***Figure 24*: Location of inanga spawning sites recorded from 1983 to 1999.**



Locating spawning sites

Generally, there are two strategies for locating inanga spawning sites; you can either search for spawning behaviour on the spring tides, or you can search the undergrowth for the tiny whitebait eggs. Spawning fish are usually more visible than the eggs (Figure 25), but even if spawning behaviour is observed, inanga often shoal in areas where they don't eventually spawn. Egg searches must take place soon after spawning (i.e., in less than 3 days) as the eggs quickly disperse down through the vegetation and become too difficult to find. Egg searches may also be slow, backbreaking work. The best approach depends on the size of the catchment, and your familiarity with it. For large or unfamiliar catchments, a high tide reconnaissance allows observers to:

- cover large areas of big catchments, especially with a boat,
- get a grasp of the high tide levels and to establish the limit of saltwater intrusion,
- locate structures such as flood gates that may truncate saltwater intrusion,
- identify and eliminate unsuitable areas from more detailed searches.

Figure 25: **Inanga eggs in riparian grass.**

Small catchments may not warrant a high tide search. Depending on catchment slope and the magnitude of local spring tides, areas subject to the saltwater intrusion may be sufficiently small to conduct an egg search at low tide, using plant distributions to indicate the upper limit of the saltwater wedge. If you are checking a site that has already been identified, then a low tide search provides the most information for the least effort by allowing positive identification of whitebait eggs and the extent of the spawning area to be determined.

Equipment

The following equipment is recommended for high and low tide searches. Safety equipment, such as lifejackets, would also be required where appropriate.

High tide searches

- Boat
- Polaroid glasses (to reduce glare and thus improve chances of seeing fish)
- Conductivity meter
- Thigh waders
- Camera
- GPS receiver (preferably with at least 8-channel performance and NZMG output. GPS fixes (often called waypoints or marks) can be downloaded into computer mapping packages that are frequently used by resource managers. In this format, spawning grounds become apparent to resource managers, and the information can be disseminated to other agencies.)
- Maps
- Waterproof inanga spawning database form (see Appendix 1)

Low tide searches

- Thigh or chest waders
- Camera
- GPS receiver or stakes to mark the site
- Maps
- Waterproof inanga spawning database form

- Latex gloves (to provide protection from soil pathogens; particularly important in urban areas with high pedestrian traffic.)
- Film canister, tissue paper, and small paintbrush (for transporting eggs to check identity and developmental stages under a microscope. Novices may confuse slug eggs with inanga eggs.)

When, where, and what to look for

When

The best time to locate inanga spawning sites is from February to April inclusive on the days following a series of spring tides (Figure 26). However, spawning has been reported in most months of the year. For example, there has been intensive spawning in Hawke's Bay in November.

Generally, inanga spawn 1 or 2 days after the new or full moon (Figure 27), and spawning is usually reported after high water as the outgoing current begins to increase at the site (Figure 28). However, there are also records of spawning well after the tidal peak and in non-tidal water, so spawning behaviour is variable. Spawning can take as little as 10 minutes or can last for over an hour.

Where

Areas near the limit of the spring-tide saltwater intrusion, but with freshwater bank vegetation, are often good areas to begin searching. Most spawning sites, but not all, are found within 500 m of the upstream limit of the saltwater wedge (Figure 29). Often there may only be a trace of saltwater present in the deepest part of the riverbed with entirely fresh water along the riverbank. However, if spawning habitat is not available at this point, then inanga may choose suitable areas either up or down stream.

***Figure 26*: Tidal cycle over a hypothetical month during the spawning season. Searching on the days following the peak of the second, higher spring tide would offer the best chance of observing inanga spawning behaviour.**

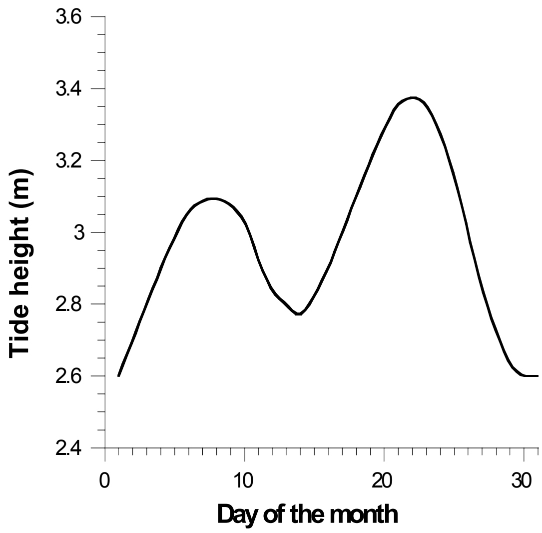


***Figure 27*: Relationship between the amount of spawning activity and moon phase (data from the national inanga spawning database). 1, lowest spawning activity score (no active spawning but pre-spawning shoals present); 6, highest score (shoals of more than 10 000 fish present with intense, noisy, spawning activity occurring.**

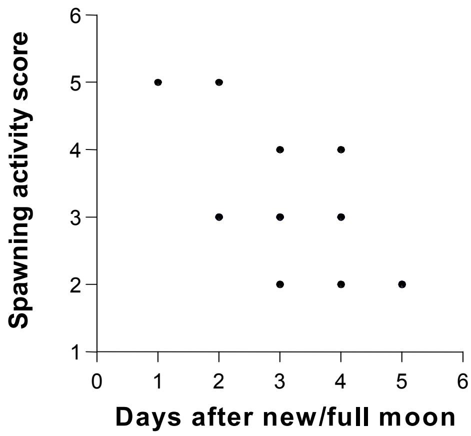


Figure 28: **Timing of the onset of spawning in relation to the turning of the tide (data from the national inanga spawning database).**

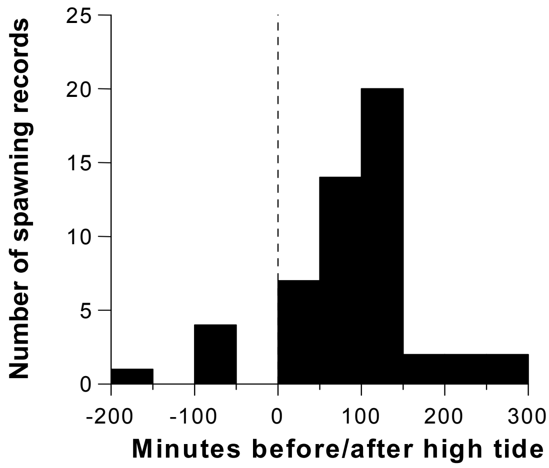
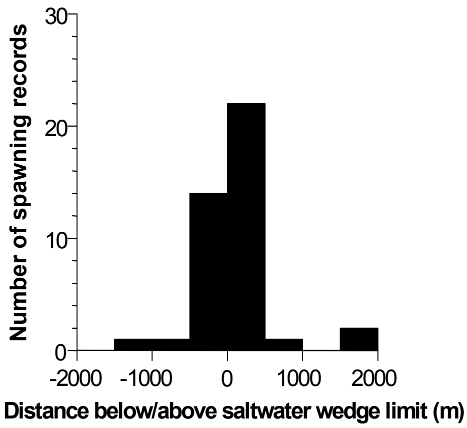


Figure 29: **Distribution of spawning sites about the upper limit of the saltwater wedge (data from the national inanga spawning database).**



If you have access to a boat and conductivity meter, use these to determine the limit of saltwater intrusion. Take conductivity/salinity readings in the middle and at the bottom of the water channel, and if conductivity/salinity rises steeply near the river bottom, then salt is present. If this equipment is not available, look for the downstream limit of the ubiquitous freshwater aquatic plants *Elodea canadensis*, *Potamogeton cheesemanii*, or *P. crispus* (Figure 30) as they do not tolerate prolonged exposure to saltwater. Another good environmental cue is the upstream limit of estuarine crab holes.

Other features often associated with spawning sites are bank embayments, tributary confluences, or obstructions that break the water current. Ripe fish often school in areas of quiet flow. In large catchments, check small, stable tributaries of the main river as these afford habitat less prone to flooding than the main stem. Depending on their slope and size, the saltwater limit of these tributaries may be much closer to the sea than in the main river.

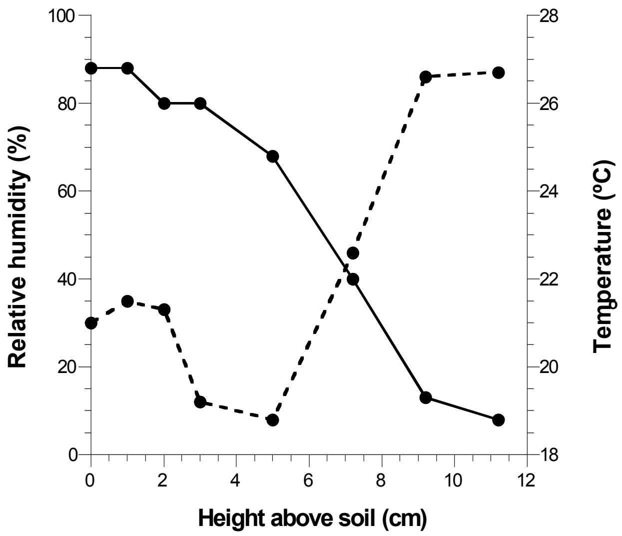
Inanga populations often thrive in lowland lakes. In Otago, eggs were found in typical spawning vegetation near the outlets of Lakes Waihola and Waipori, and also around the edge of Lake Waihola. In Canterbury, eggs were found amongst raupo and grass in a spring-fed inlet of Lake Ellesmere. Spawning within the lake was controlled by water levels dictated by the prevailing wind direction, and was out of phase with the tidal cycle. Similar spawning sites may also occur in other wind-exposed lakes where there is saltwater intrusion.

Figure 30: **Aquatic plants that indicate the limit of saltwater intrusion: left to right, *Elodea canadensis*, *Potamogeton crispus*, and *P. cheesemanii*.**

What to look for

Because inanga lay their eggs above the normal river level, vegetation is necessary to shelter the eggs from drying and from temperature extremes (Figure 31). Therefore, any rank vegetation that traps moisture close to the soil surface should be checked. This normally precludes riparian margins that are grazed, but check areas where livestock have little access or where the bank is unsuitably steep for stock. Inanga eggs are commonly found on a number of exotic and native riparian plants (Table 1). However, other plants may be used, and occasionally inanga eggs have even been found on mosses.

Figure 31: **Relationship between relative humidity (solid line), air temperature (dashed line), and the height above the soil in vegetation at an inanga spawning site, 10 April 1995.**



If you are searching for spawning activity on the high tide, it pays to be as quiet as possible because it is often easier to hear spawning activity than it is to see it. You may also hear and see predating animals such as birds (shags, ducks, and herons), other fish (especially eels and trout), and even stoats feeding on spawning inanga. If you part the inundated vegetation, you may observe adult inanga in the shallows, and amongst the litter layer. The water may be discoloured with milt (fish sperm), and thus appear milky white (Figure 32).

If you are conducting an egg search at low tide, it is important to part the vegetation with sufficient force so that you can see the soil surface. Most eggs will be close to the soil surface, but some may be adhering to the vertical stems (see Figure 25). This process can be backbreaking, and on steep banks it is sometimes more comfortable to stand in the water to search the banks. Measure or estimate the approximate bank area used for inanga spawning. Typically the zones are narrow (depending on bank slope) and sometimes long. Obtain a GPS location fix, preferably using NZMG coordinates.

***Table 1*: Plants commonly associated with inanga eggs.**

	Common name	Scientific name	Where eggs are commonly found
Introduced grasses	Tall fescue	*Festuca arundinacea*	Around the root hairs or on the decaying grass blades around the base
	Creeping bent	*Agrostis stolonifera*	Under the mat of runners that forms on the soil surface
	Yorkshire fog	*Holcus lanatus*	On the soft hairs on the leaves and stems
	Twitch, couch	*Agropyron repens*	On the thick root mat
	Cow parsley	*Apium nodiflorum*	Attached to roots and stems
Herbs	Monkey musk	*Mimulus guttatus*	On the floating stems and root hairs
	Lotus	*Lotus* sp.	Attached to roots and stems
	Buttercup	*Ranunculus repens*	Attached to root and stems
	White clover	*Trifolium repens*	Attached to roots and stems
	Peppermint	*Mentha* x *piperita*	Attached to roots and stems
Native grasses	Wiwi	*Juncus gregiflorus*	Around bases and lower stems
	Jointed rush	*Juncus articulatus*	Around bases and lower stems
	Flax	*Phormium tenax*	Around bases, often in association with grasses in the periphery
	Raupo	*Typha orientalis*	Attached and under decaying leaves
	Umbrella sedge	*Cyperus eragrostis*	Around base of plant

Figure 32: Milt from spawning inanga.

Spawning site management and enhancement

Inanga spawning sites need to be actively managed because very often a successful spawning ground may not stay that way. Pastoral grasses may be overshadowed by willow, blackberry, and gorse, or overrun by weeds like old man's beard, wandering Jew, Mercer grass, thistle, or *Glyceria*. Livestock could trample the site, and near roads and in urban areas, oil or chemical spills could kill the eggs. Well-meaning regional authorities often mow stream banks to stubble, reducing their viability for spawning. Usually these activities occur in ignorance of the ecological importance and sensitivity of the site, so it is important that the site is registered and local land and water managers informed.

Spawning sites can be registered by completing the inanga spawning survey form (Appendix 1) and submitting this (and any photographs) to Mark Taylor at Aquatic Ecology Ltd., P.O. Box 5032, Christchurch. The spawning site may already be known, but it is useful knowing the site is still being used. It is important to think about any perceived threats to inanga egg survival and to enter these in the appropriate section on the form. Mark will process the forms and enter them onto the national inanga spawning site database. Some regional councils include the GPS location on a GIS layer of ecologically sensitive habitats, or even gazette such sites.

Management is relatively straightforward. If the land is grazed, livestock should be excluded from the site before and during the spawning season. This allows bank vegetation to attain some height before spawning and ensures that the eggs do not get trampled after they are laid. Mitchell (1991) found that more spawning occurred on sites where livestock had been excluded for 18 months and vegetation height was 1.5 m than on grazed sites where vegetation was less than 0.3 m high. At some sites, occasional grazing in winter and spring might be required to keep woody plant species from displacing suitable grasses.

In urban areas, interpretation signs, bollards, and long grass are usually sufficient deterrents to prevent pedestrians from trampling eggs. However, spawning sites in urban areas are subject to high numbers of wind-borne and water-borne seeds, and therefore will need to be weeded from time to time. Blackberry and crack willow are unwelcome adventives in urban areas, and gorse can be a problem in rural areas. All of these plants (and many others) have the potential to reduce a spawning site’s suitability by reducing vegetation growth under their respective canopies. Gorse can be a friend rather than a foe if it can be constrained to form a stock fence around the spawning ground boundary.

It is possible to improve spawning areas to attract larger numbers of fish so that more eggs are deposited. At the most intensive level, this may require recontouring the bank, and resowing the area with vegetation that is more suitable for spawning. This has been carried out successively in both the North Island and the South Island. For example, protection and management of spawning sites in Hawke’s Bay have coincided with substantial improvements in the whitebait fisheries in the Tutaekuri, Tukituki, and Ngaruroro Rivers since 1987 (H. Rook, DOC, pers. comm.). In 1995, the Christchurch City Council regraded and replanted a stream bank with separate embayments containing exotic grasses and native plants (Figure 33). After several years of botanical development, inanga resumed using the site, to the point that the site has recently been extended.

***Figure 33*: Restored inanga spawning site (with interpretation sign arrowed) on the Heathcote River in Christchurch.**

Summary

We hope the guidelines provided in this document will instigate inanga restoration projects. For adult habitat, stream location and morphology are critical factors that cannot be altered. Generally, only low altitude streams less than 10 km from the coast should be considered for restoration. Access and cover are also very important, but can be improved or restored. Water quality is probably the least important factor, and if smelt or common bully are present, then water quality is already suitable for inanga.

Identification and registration of inanga spawning sites is the first step toward protecting these critical habitats. After that, ensuring the vegetation remains suitable for egg development may require active management of the site. Suitable sites can also be restored by bank contouring and replanting of appropriate vegetation.

Inanga habitats can often be relatively easily protected and improved by restricting livestock access to the stream banks. Cover, water quality, and spawning vegetation will all benefit from allowing the riparian vegetation to regrow, within limits. Allowing or assisting meander patterns to develop will create the flow conditions that inanga prefer and reduce the effect of floods. Although improvement and restoration projects may be challenging and long term, the benefits to the whitebait fishery can be enjoyed by all New Zealanders.

Acknowledgments

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Appendix 1

Example of a completed inanga spawning survey form. These forms are available from Mark Taylor at Aquatic Ecology Ltd, P.O. Box 5032, Christchurch, and should be sent to him after being filled in for site registration.

CONSERVATION TE PAPA ATAWHAI

INANGA SPAWNING SURVEY

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

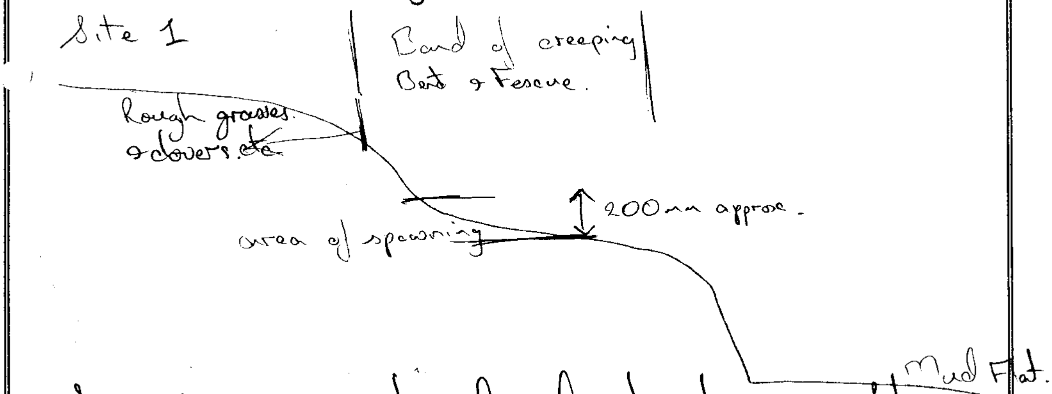
NIWA
Taihoro Nukurangi

SITE LOCATION DATA			Number: 424
Survey date 26-3-97	Map sheet No. NZMS(260) S24.	Easting: 27 014	Northing: 60760.
Surveyors' name: Tom Rouse.	Contact address: DoC. PB11010. Palmerston North.	Survey agency: DOC	Catchment No. (if known) 325 000
Catchment name: Manawatu.		Surveyed bank length (m):	
Locality: Whirokino Cut.			
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 10 (m²)	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: South bank. - Crown Lease Forest (Wataree) North bank. - Leased to Richard Anderson. by MWRC.	
Predominant land use Urban / Wasteland / Reserve / Industrial / Recreational / Pastoral / Other	Spawning vegetation code numbers (key overleaf) Grasses 1 & 2	Herbs 2 & 4.	Native vegetation Nil
Nature and extent of perceived threats to spawning	Flooding.		

SPAWNING SITE SKETCH



Notes: Spawning was only found at site 1. Site 2 is now breadly layered grasses & herbs. Site 3. a fenced off area was saturated and has been regularly covered with flood waters. No eggs found at This site.