NIWA
Taihoro Nukurangi

Dune lake galaxias in the Kai Iwi Lakes

Review of status and development of a long term monitoring plan

Prepared for Northland Regional Council

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Executive summary

The Kai Iwi Lakes are recognised for their ecological, cultural and recreational significance in the region of Northland. They are home to the dune lakes galaxias (DLG), an endemic landlocked member of the *Galaxias maculatus* species complex. The DLG population in the Kai Iwi Lakes declined at a time when both trout and gambusia were introduced to the Lakes. Northland Regional Council is committed to reducing the threat status of threatened species, working in cooperation with the Department of Conservation. There is a proposal by Kaipara District Council to discontinue the stocking of trout in the Lakes. As such, Northland Regional Council contracted NIWA to review the status of DLG in the Kai Iwi Lakes, the potential impact on the DLG population of interactions between DLG and exotic fish species in the Lakes, and to make recommendations or a program of long-term monitoring of DLG in the Lakes. This report therefore contains:

- a review of the literature and all available fish data on the status and ecology of dune lake galaxias in the Kai Iwi Lakes/Taharoa Domain
- a critical evaluation of the available information on biotic interactions between dune lake galaxias and exotic fish species in the Lakes, in particular trout and gambusia, and
- recommendations for a suitable long-term fish monitoring plan for the Lakes.

The Kai Iwi Lakes population of DLG has been recognised as an evolutionarily significant unit of the *Galaxias maculatus* species complex, and work is currently underway to describe it as a separate species. DLG currently has a conservation status of “At risk”. Ongoing monitoring of the population demonstrates that inter-annual abundance is highly variable and numbers remain small. The population is currently restricted to lakes Taharoa and Waikare, and is consequently at a high risk of extinction.

DLG spawns over an extended period, most likely through autumn and early winter, and likely uses emergent vegetation in the littoral zone for spawning. Larvae are pelagic and dispersed throughout the limnetic zone. Schools of juveniles feed on zooplankton in the upper pelagic zone, while small adults inhabit the littoral zone and feed on small invertebrates. Larger adults inhabit the deeper pelagic zone during the day, but return to the littoral zone at night to feed.

Trout were introduced to the Lakes in 1968 and have continued to be stocked in the Lakes for recreational fishing. Gambusia were first noticed in the Lakes in 1971. Both species have subsequently been found to have a negative impact on the DLG population, which declined sharply in the late 1960s and early 1970s, and has remained low since. Trout are known predators of DLG and gambusia compete for habitats and food. It has been hypothesised that trout reduce the negative impact of gambusia on DLG, however, as yet there are is little supporting evidence for this theory. Floristic, chemical, and hydrological factors may also influence the abundance of DLG, however, there is a lack of understanding of the precise factors and the nature of any relationships with DLG abundance.

Cessation of trout stocking in the Lakes would undoubtedly remove a predator and a negative influence on the DLG population. However it would be advisable to address the remaining ambiguity over the effects of trout on the gambusia population before ceasing trout stocking.

We recommend that detailed long-term monitoring focuses on relating the variability and trends in abundance of DLG with likely factors influencing their abundance, including the abundance of both trout and gambusia in the Lakes. The monitoring program should include three-monthly catch per unit effort surveys of gambusia and common bully, both visual and quantitative surveys of DLG, yearly estimates of the trout population from angler returns, an annual eel survey, locating and monitoring DLG spawning sites, and monitoring of water levels and extent of littoral spawning vegetation in the Lakes. This will provide an ongoing record of the status of DLG and will provide information that can be used to direct management actions and improve management outcomes. In addition, experimental trials investigating the interaction between trout and gambusia may also be beneficial to clarify their relative impacts on DLG.

1 Introduction

1.1 Background

Objective 3.4 of the Northland Regional Policy Statement requires that Northland Regional Council (NRC) safeguard and enhance the ecological integrity of indigenous freshwater ecosystems and seek an overall reduction in the threat status of threatened and at risk species (Northland Regional Council 2016a). The Kai Iwi Lakes are identified as highly significant in the Northland Lakes Strategy (Champion and de Winton 2012), and are designated collectively as an outstanding water body in the draft Northland Regional Plan (Northland Regional Council 2016b) for their ecological, cultural and recreational significance.

The Lakes are home to the dune lakes galaxias (*Galaxias sp.*) (DLG), a fish species that is endemic to the lakes. The DLG is now found only in Lake Taharoa and Lake Waikare, although they were historically also present in Lake Kai Iwi (Rowe 1998). Dune lakes galaxias is currently listed in the New Zealand Threat Classification System as "At risk – Naturally Uncommon" for reasons of range restriction and extreme fluctuations in population size (Goodman et al. 2014). NRC, therefore, have an obligation under the requirements of the Regional Policy Statement to safeguard the status of the DLG.

The Northland Lakes Strategy (Champion and de Winton 2012) recommended the development of management plans for all outstanding lakes in Northland with the objective of identifying priority actions for each lake. Furthermore, it was recommended that the ecological status and water quality of the Lakes should be assessed, and a biosecurity action plan should be developed. Management plans are to be developed this year for the three Kai Iwi Lakes, and will complement the Reserve Management Plan for the Kai Iwi Lakes/Taharoa domain recently developed by the Kaipara District Council (Kaipara District Council 2016). One of the objectives identified in the reserve management plan is to improve knowledge of the native and exotic fish communities in the Lakes, and to cease the stocking of trout in the Lakes by 2018.

To help fulfil its obligations under the Regional Policy Statement, NRC contracted that NIWA to undertake a review of the status of the dune lake galaxias and critically evaluate the potential effects on their status resulting from their interactions with the exotic fish species present in the Lakes. Furthermore, NRC has requested advice on a suitable monitoring programme to support future management of this unique species.

1.2 Scope

The scope of this report is to provide:

- a review of the literature and all available fish data on the status and ecology of dune lake galaxias in the Kai Iwi Lakes/Taharoa Domain
- a critical evaluation of the available information on biotic interactions between dune lake galaxias and exotic fish species in the Lakes, in particular trout and gambusia, and
- recommendations for a suitable long-term fish monitoring plan for the Lakes.

2 Kai Iwi Lakes/Taharoa Domain

The Taharoa Domain encompasses an area of approximately 538 ha in the Kaipara district in Northland, and includes three lakes – Lake Waikare, Lake Taharoa, and Lake Kai Iwi (Kaipara District Council 2016). The Lakes have no permanent tributaries and no outflow (Rowe 2002), although Lake Kai Iwi is believed to have historically had an outlet to the sea (Rowe pers. comm. 2017). Lake Taharoa is the largest of the lakes, with an area of 2.11 km^2, and a maximum depth of 39 m (de Winton et al. 2015). Lakes Waikare (0.32 km^2) and Kai Iwi (0.31 km^2) are smaller, but Waikare has a maximum depth of 30 m compared with only 16 m in Lake Kai Iwi. Lake Kai Iwi is intermittently connected to Lake Taharoa via a culvert that joins the two when lake water levels are high. Lake Taharoa formed at least 50000 years ago (Mosley 2004), and Kai Iwi and Waikare may have formed at a similar time, although most dune lakes are substantially younger, around 6500 years old (Lowe and Green 1992 in Mosley 2004).

In a 2006 survey of the nutrient status of the Lakes, Kai Iwi and Waikare were found to be mesotrophic, while Taharoa was oligotrophic (Northland Regional Council 2006). All three lakes stratified in the summer, with moderate deoxygenation of the bottom waters in Lakes Kai Iwi and Taharoa, and anoxic conditions developing in the bottom waters of Lake Waikare. The littoral vegetation of the Lakes is comprised of three main species – *Leptocarpus similis*, *Baumea arthropylla* and *Eleocharis sphacelata* (Rowe et al. 1999). Lake Kai Iwi has an almost continuous vegetated littoral zone (approximately 80%), whereas the littoral zones of Lakes Waikare and Taharoa consist of patches of vegetation covering around 25% of the littoral zone, in addition to sandy beach areas (Pingram 2009).

The fish fauna of the Kai Iwi Lakes comprises the DLG (*Galaxias* sp.), the common bully (*Gobiomorphus cotidianus*), longfin eel (*Anguilla dieffenbachii*), shortfin eel (*Anguilla australis*), rainbow trout (*Oncorhynchus mykiss*), and gambusia (*Gambusia affinis*). Trout cannot breed in the Lakes, and so the population is maintained by annual stocking in Lakes Waikare and Taharoa by Northland Fish and Game.

The three Kai Iwi Lakes differ significantly from each other when the combination of aerial size, depth, and littoral vegetation coverage of each lake is considered. This has important implications for the management and monitoring of DLG. Unfortunately, it also means that for any experimental changes in the management of DLG populations, no lake makes for a good control case to compare to the lake impacted by the management changes. In terms of monitoring the DLG populations, the differences between the lakes and the lack of a surface water connection between Lakes Taharoa and Waikare mean that it is important to monitor the fish populations of each lake separately.

3 Status and ecology of dune lakes galaxias in the Kai Iwi Lakes/Taharoa Domain

3.1 Taxonomic status of dune lakes galaxias

The DLG forms part of a non-migratory species complex derived from inanga (*Galaxias maculatus*), but its taxonomic status has remained unresolved for a number of years (White et al. 2014). Whether the Kai Iwi Lakes galaxias populations represent an evolutionally significant unit (ESU), and are distinct from dwarf inanga (*Galaxias gracilis*), has a critical bearing on how the population should be managed. For the purpose of this project, therefore, a summary of the key discussions regarding the taxonomic status of the dune lake galaxias is provided below.

In 1950, land-locked populations of unidentified galaxiids were discovered in 10 lakes on the west coast of New Zealand's North Island (Cunningham 1953, cited in Rowe and Chisnall 1995). McDowall (1967) inspected samples of these galaxiids from Lake Rototuna and determined them to be most closely related to *Galaxias maculatus*, however, due to morphometric differences he described them as a new species – *Galaxias gracilis*, dwarf inanga. Subsequently, dwarf inanga were found to naturally occur in 11 lakes along an 80 km stretch of the Northland coastline (Rowe and Chisnall 1997) – the Kai Iwi Lakes (Kai Iwi, Waikare and Taharoa), and the Pouto Lakes (Rototuna, Rotopouna, Rotootuaru, Humuhumu, Rotokawau, Waingata, Kanono, Kahuparere). In addition, they have been introduced to Lake Rototoa and Lake Te Riu, the latter as part of a conservation programme (Department of Conservation 2008a).

Despite the morphological similarities between populations of dwarf inanga, genetic analyses have indicated the populations across the different lake systems have likely derived from three separate founding events (Ling et al. 2001). Consequently, three separate ESUs of dwarf inanga have been recognised; the Kai Iwi Lakes population, the Lake Rototuna population, and those populations that inhabit the southern Pouto Lakes on the North Kaipara Head and Lake Rototoa (Ling et al. 2001). The population in Lake Te Riu was not included, however, it would presumably be included with the Kai Iwi Lakes population as it is translocated from Lake Waikare. Although these initial investigations found that the populations were not sufficiently genetically distinct from each other and from the founding taxon, *Galaxias maculatus*, to warrant treatment as separate species (Ling et al. 2001, White et al. 2014), the Kai Iwi Lakes dwarf galaxias ESU has been determined as the most genetically distinct group, being derived from the oldest founding event. For conservation purposes it has been treated as a separate species, the dune lakes galaxias (Kai Iwi Lakes) (*Galaxias* "dune lakes"), by the Department of Conservation since the early 2000s (Allibone et al. 2010, Goodman et al. 2013), and work is currently underway to formally recognize the DLG as a distinct species (Ling, pers. comm. 2016).

A salient point from the recent genetic work by White et al. (2014) is that the Kai Iwi Lakes DLG population is more closely related to diadromous inanga than to the landlocked dwarf inanga found in the Poutu Lakes or the landlocked inanga found in Lakes Ngatu, Waiparera and Tokerau in the far north. While these populations stem from the same parent taxon and probably have similar ecology due to inhabiting similar lacustrine environments, we have drawn wherever possible in this report from what is known about the Kai Iwi Lakes ESU, rather than from observations of other landlocked inanga or dwarf inanga populations. Nonetheless, much of the known ecology of DLG comes from studies prior to the genetic distinction between DLG and dwarf inanga. In addition, as noted by Ling et al. (2001) there are notable morphological differences between landlocked and diadromous populations of *G. maculatus* across the widespread geographical range of the species, which suggests "quite characteristic ontogenic effects associated with a loss of diadromy". Where the term "dwarf inanga" is used in this report, it refers to what is thought to be common ecology of the small land-locked galaxiids related to *G. maculatus*; "DLG" is used where aspects of ecology have been observed directly from the Kai Iwi Lakes population.

3.2 Ecology of the dune lakes galaxias

McDowall (1990) suggested dwarf inanga grow to a length of up to 55 mm, with maturity reached around 30 mm, however DLG as large as 70 mm have been observed (Rowe 1998).

Rowe and Chisnall (1995) undertook a study of dwarf inanga in Lake Kanono to describe the basic ecology and biology. Larval dwarf inanga were planktonic and found to a depth of at least 10 m in spring (Rowe and Chisnall 1995). Post-larvae up to 41 mm were observed in the top 3 m of the pelagic zone. Catch rates of the larger post-larvae (27 – 41 mm) were typical of schooling fish. Schools of large adult dwarf inanga (over 60 mm) were observed in the deep pelagic zone during the daytime, and had disaggregated and migrated to the littoral zone by night. Smaller adults were observed in the littoral zone during both the day and the night. Juvenile dwarf inanga were found to feed on zooplankton in the limnetic zone, predominantly the cladoceran *Bosmina*, but also calenoid copepods (Rowe and Chisnall 1995). Adults fed in the littoral zone on larger invertebrates including mites, chironomid larvae, pea mussels, as well as other unidentified larvae and terrestrial insects.

A study of DLG in Lake Waikare largely confirmed the transferability of the findings on the basic ecology of dwarf inanga to DLG. Pingram (2005a) found that DLG diet was dominated by cladocera and terrestrial invertebrates, with other prey items including molluscs, hydracarina, aquatic dipteran larvae, copepods and ostracods. In Lake Waikare, DLG were observed to school during the daytime and disaggregate at night.

Despite several attempts to better understand the reproductive cycle of DLG, spawning times remain unclear, and spawning location unknown. In the dwarf inanga population in Lake Kanono, Rowe and Chisnall (1995) noted a bi-modal distribution in the age of post-larvae, suggesting two spawning events. In the same study, they observed in March that some males were ripe, but many were still in the final stages of gonadal development, leading them to conclude that spawning occurs after March. Similarly, in Lake Waikare, estimated hatch dates from DLG collected in 2003 – 2004 had a wide, somewhat bi-modal, distribution (Pingram 2005). Pingram deduced from this an extended spawning period from summer to early winter with a peak in June, based on the assumption of a 20 – 30 day egg development period (similar to *G. maculatus*). This assumption has been criticised in light of the variability in egg development times with temperature, with the implication that a shorter egg development time would shift the spawning period closer to mid-winter (Rowe 2016). Based on the observations of larval DLG, spawning is likely to be occurring between late summer and winter. Rowe et al. (1999) observed larvae in Lake Waikare in September. Recent surveys have observed peaks in larval densities in June – August in Lake Waikare, and August – November in Lake Taharoa in 2005 – 2010, noting that these are quite large larvae and post-larvae (up to 25mm) (Pingram 2009, Department of Conservation unpublished data 2017). Rowe and Chisnall (1996) estimated fecundity to be quite low, in the order of 500 eggs per female.

Based on the known spawning habitat of diadromous inanga, Rowe and Chisnall (1997a) asserted that DLG are likely to spawn in the littoral zone, most probably on emergent macrophytes in the deeper sections to reduce exposure during periods of low lake levels. Comparing a range of lakes in which dwarf inanga were present, they noted that sandy beaches did not appear necessary for spawning, and that the native submerged macrophyte *Chara globularis* was present in lakes where dwarf inanga were common, and was absent where dwarf inanga were rare, and it may provide spawning habitat although the association may be coincidental.

The basic life-history of DLG can be summarised as follows: spawning likely occurs in the littoral zone, probably amongst emergent vegetation, most likely in autumn or early winter; larvae are pelagic and dispersed throughout the limnetic zone; schools of juveniles feed on zooplankton in the upper pelagic zone; small adults inhabit the littoral zone and feed on small invertebrates; and larger adults inhabit the deeper pelagic zone during the day, but return to the littoral zone at night to feed.

3.3 Conservation status of the dune lakes galaxias in the Kai Iwi Lakes

The historical distribution of the DLG included all three Kai Iwi Lakes – Kai Iwi, Taharoa, and Waikare (Allen and Turner 1971). However, it has since been extirpated from Lake Kai Iwi (Rowe 1998). The species may also have been present in nearby Shag Lake, based on oral history from a reliable local source (see commentary in Rowe and Chisnall 1997b).

Reporting on the 1971 trout survey of the Lakes, Allen and Turner (1971) noted seeing 30 – 40 DLG in Lake Waikare, and 10-15 in Lake Kai Iwi. No DLG were observed in Lake Taharoa, and none were observed in the stomach contents of trout captured in that lake. They compared these observations with observations from 2 years prior, which indicated that DLG were "fairly common" in Lake Taharoa. Cudby and Ewing (1969, cited in Allen and Turner 1971) had found DLG in the stomachs of 22% of trout sampled from Lake Taharoa. It is clear from these early observations that the population of DLG decreased notably over the period 1969 – 1971. Surveys conducted in 1985 and 1991 – 1992 found DLG in Lakes Taharoa, Waikare and Kai Iwi, however, the species was rare in the Lakes by the 1991 – 1993 surveys, and considered under threat (Rowe and Chisnall 1997b, MacDonald 2009). In 1993, no DLG were found at all in Lake Kai Iwi, although Rowe (1998) notes that this may have been due to the sampling protocol. In 1998, an extensive search of Lake Kai Iwi failed to detect any DLG and they were presumed to be extirpated from the lake. Management trials in 1993 – 1998 involved the suspension of trout stocking in Lake Waikare, and although the overall population of DLG appeared to increase from 1995 – 1997, the abundance of adult DLG remained rare during this time (Rowe et al. 1999). The trial was suspended over concerns that the population of gambusia was increasing as a result of the reduced trout numbers (further details of this study are discussed in Section 4.1).

After the genetic and meristic analyses of Ling et al. (2001), the Kai Iwi Lakes population of DLG was identified in the 2004 New Zealand non-migratory galaxiid recovery plan as a separate species from dwarf inanga, warranting specific actions for conservation (Allibone and Barrier 2014). Visual surveys of the DLG populations in Lakes Waikare and Taharoa were carried out four times per year from 2003 – 2012 and sporadically since then, with a view to understanding changes in the abundance of DLG in the Kai Iwi Lakes (Pingram 2005a, MacDonald 2009, Department of Conservation unpublished data 2017). These surveys are qualitative and do not give a quantitative measure of the total number of DLG in the Lakes, but are useful for understanding crude temporal changes in relative abundance (MacDonald 2009). Figures 1 and 2 illustrate the high degree of variability in the size of the populations in Lake Waikare and Taharoa, which makes it difficult to confidently detect trends in populations. Nevertheless, results suggest that only quite small populations of DLG still exist in Lakes Waikare and Taharoa (MacDonald 2009).

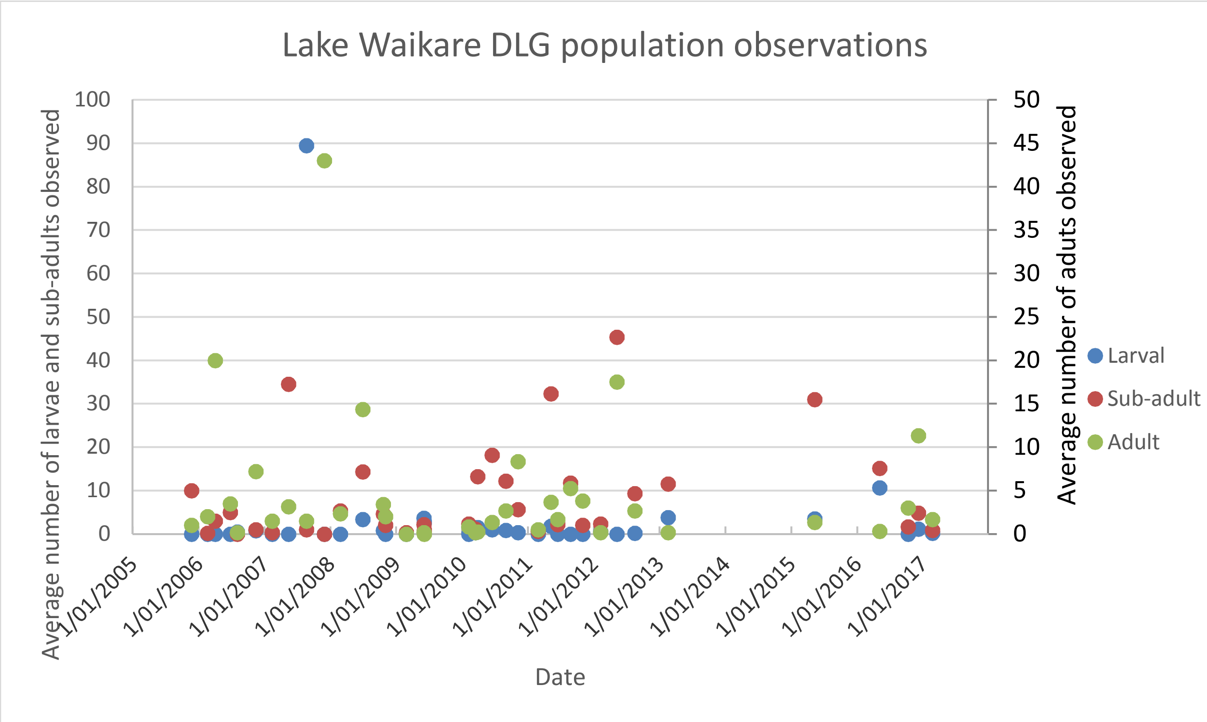

Figure 1: **Average number of dune lake galaxias observed in Lake Waikare between 2005 and 2017.** Data from Pingram (2005b), Pingram (2009), Department of Conservation unpublished data (2017).

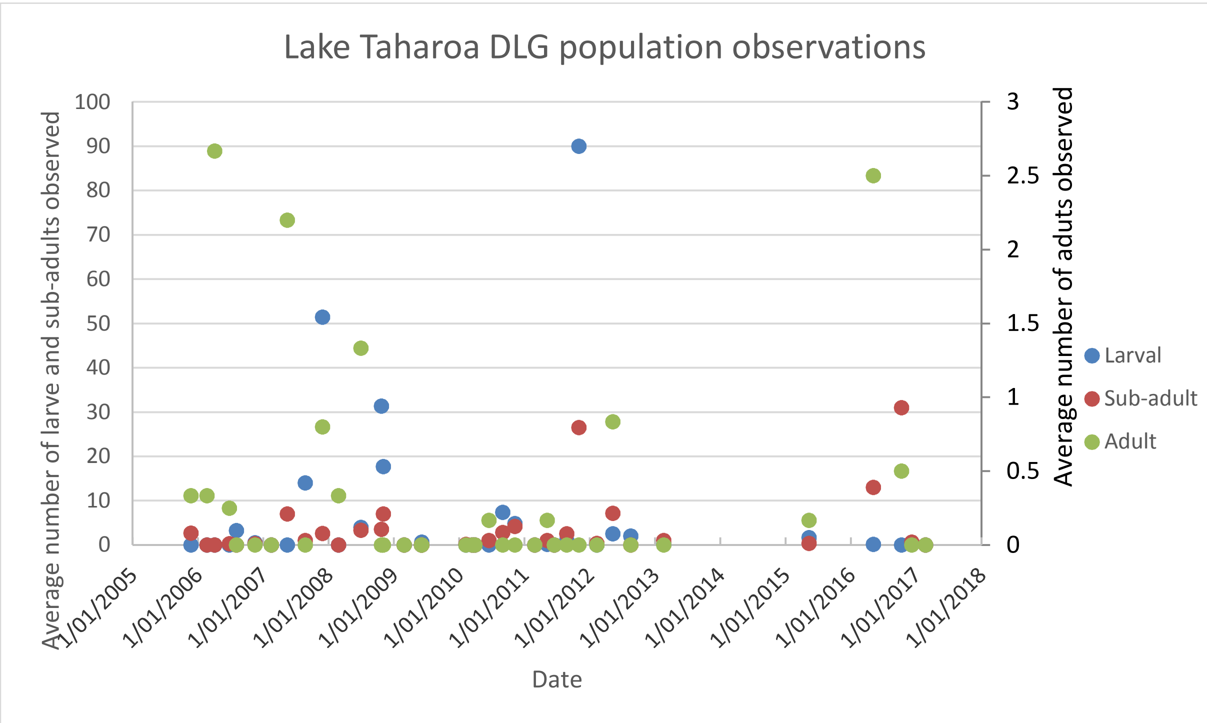

Figure 2: **Average number of dune lake galaxias observed in Lake Taharoa between 2005 and 2017.** Data from Pingram (2005b), Pingram (2009), Department of Conservation unpublished data (2017). Note the difference in scale for the adult numbers compared to Figure 1.

Figures 3 and 4 illustrate the temporal variability in observing adults, sub-adults and larvae of DLG in Lake Waikare and Lake Taharoa. This has implications for the timing of surveys that form part of any future monitoring program.

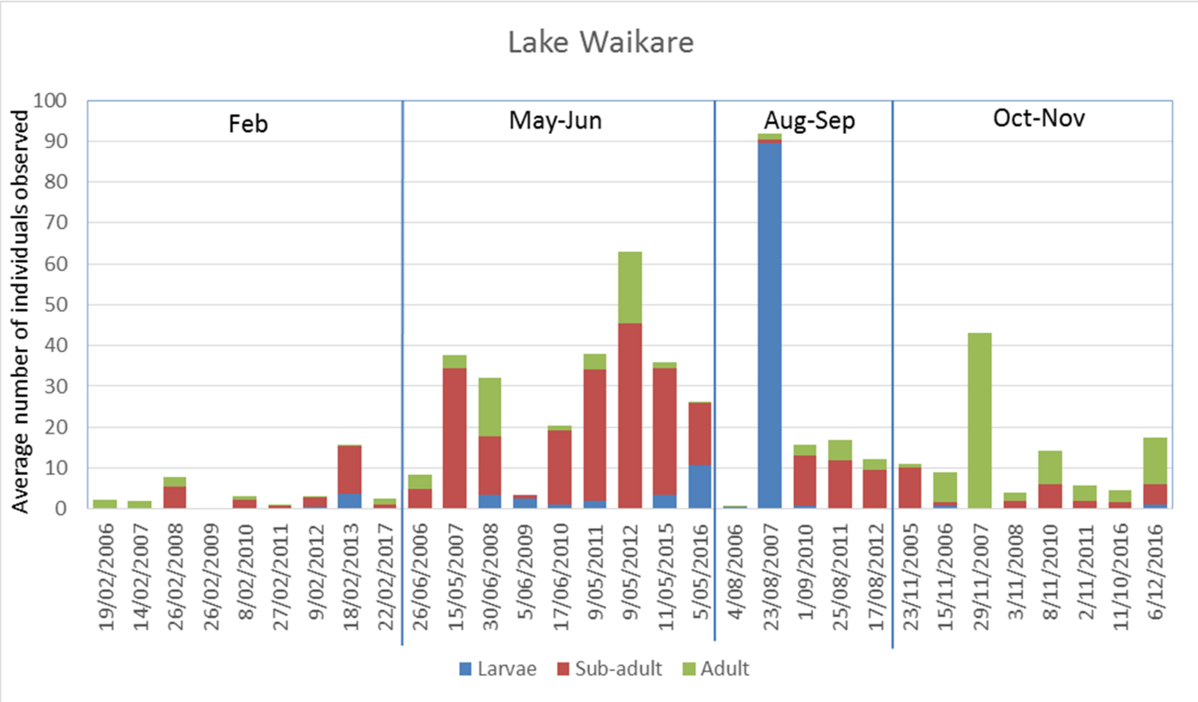

Figure 3: **Average number of dune lake galaxias observed in Lake Waikare between 2005 and 2017.**
Note: observations have been grouped by time of year.

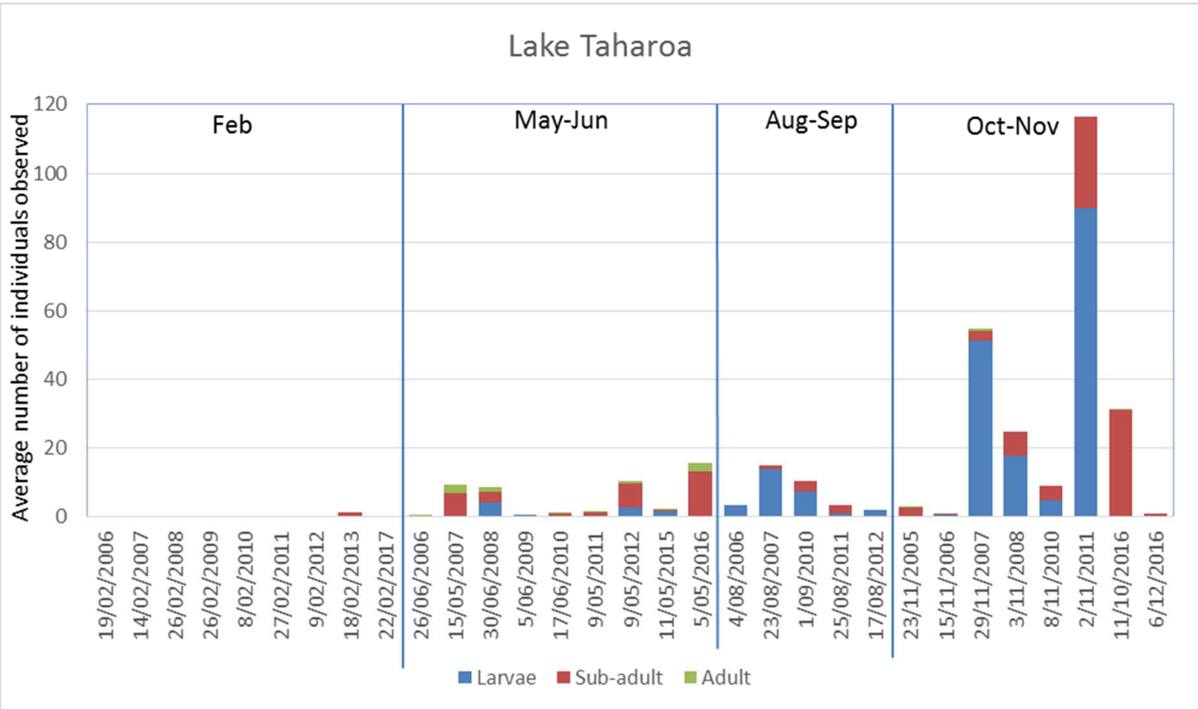

Figure 4: **Average number of dune lake galaxias observed in Lake Taharoa between 2005 and 2017.**
Note: observations have been grouped by time of year.

DLG is currently listed in the New Zealand Threat Classification System as “At risk – Naturally Uncommon” for reasons of range restriction and extreme fluctuations in population size (Goodman et al. 2014). Historic and recent data supports this classification. Rowe and Chisnall (1997a) note that effective conservation of fish populations in small isolated lakes requires the maintenance of large populations in each lake. As such it is important the conservation efforts continue, and that factors influencing population dynamics of DLG continue to be studied and evidence used to inform management decisions.

4 Biotic interactions between dune lake galaxias and exotic fish species

Understanding the impact of exotic fish species on the status of DLG in the Kai Iwi Lakes is critical to developing a successful management plan for their conservation. Two species of exotic fish are present in the Kai Iwi Lakes – gambusia (*Gambusia affinis*) and rainbow trout (*Oncorhynchus mykiss*) (Anon 1973, McEwan 2016). Both species have been suggested to have a negative impact on DLG populations, trout primarily through direct predation and gambusia through competition for food and habitat (Rowe 1997b, Pingram 2005b). However, there remains a lack of a clear consensus regarding the relative role of the two species in controlling DLG population dynamics. The following sections provide a review of the available literature discussing the biotic interactions between trout, gambusia and DLG.

4.1 Rainbow trout

Rainbow trout were first introduced to Lake Taharoa in 1968, with an initial release of 10,000 trout, followed by a further release of 5000 fish in 1969. At this time 5000 trout were also released into Lake Waikare (Allen and Turner 1971). Trout also entered Lake Kai Iwi through a small culvert connecting it to Lake Taharoa. Prior to stocking with trout, DLG were observed to be common and widespread in the Lakes (Allen and Turner 1971). Six months after the first stocking, the abundance of DLG had not changed, but after 2 years no DLG were observed and this coincided with poor condition of the released trout. In 1971, DLG were observed again, although in very low numbers, in Lakes Waikare and Kai Iwi, but not in Lake Taharoa (Allen and Turner 1971). DLG were also found in the stomach contents of trout captured in Lakes Waikare and Kai Iwi at this time.

From these early observations, it seems clear that the stocking of trout coincided with an initial decline in the population of DLG. Rowe and Chisnall (1997a) also note that more generally for dwarf inanga, a decline in population has followed the introduction of trout, and McDowall (2006) commented on the “seriously adverse impacts of trout predation on this species in other lakes”. Rainbow trout are predators of DLG, as evidenced by their presence in trout stomach contents, both historically and more recently (Allen and Turner 1971, Pingram 2005b). Pingram (2005b) identified 19 individual DLG present in trout stomachs during a fishing contest in August 2004, with an average size of 38.7 mm. He noted that DLG were present in the stomach of 25% of sampled trout and that predation could have been higher given the amount of unidentifiable fish remains in the trout stomachs. These results should also be considered in the context that the lower the abundance of DLG, the lower the chance of trout having consumed them. This was observed by Fish (1966, cited in Rowe and Chisnall 1997a) who recorded *G. gracilis* in 76% of the trout caught in Lake Waingata in 1962, but by 1963 *G. gracilis* were too scarce to be preyed on by trout. Furthermore, trout diet will vary through the year and so predation of DLG may be different at different times of the year.

Rowe and Chisnall (1995) thought that trout predation had undoubtedly contributed to the decline of dwarf inanga, but it was unlikely to be the only factor responsible for its decline. In a comprehensive review of factors influencing the abundance of dwarf inanga and DLG, it was noted that differences in trout stocking rates do not account for the differences in abundance of dwarf inanga (and DLG) between lakes across their geographic range (Rowe and Chisnall 1997b). In particular, a similar rate of trout stocking to that in Lake Waikare occurred in Lake Rototoa (which contained no *Gambusia affinis*) and had not resulted in the same level of decline in the dwarf inanga population of that lake (Rowe 2016). However, these conclusions were based on a comparison of annual stocking rates (fish/ha/yr) rather than measured densities of trout in the lakes and assume that the former is a good proxy for the latter.

Given the evidence indicating a negative impact on the abundance of DLG resulting from trout predation, a trial was undertaken in Lake Waikare to remove trout from 1993 to 1998. Stocking of trout was ceased in 1993 and gill netting was undertaken to remove the remaining trout over the subsequent years (Rowe et al. 1999). Throughout the trial the number of DLG was measured using catch per unit effort (CPUE) data from nocturnal fyke netting, plankton trawls and seine netting. During this trial, numbers of juvenile DLG increased, but an equivalent increase in the adult population failed to emerge. CPUE of adult DLG remained similar in Lake Waikare to that in Lake Taharoa, in which trout continued to be stocked. While the catch per unit effort data is not directly comparable to more recent visual surveys, it displays the same high degree of inter-annual population variability which makes the detection of trends over five years difficult. The results of the trial show that trout do have a negative impact on juvenile DLG survival, but they are likely not solely responsible for the low number of adult DLG. Rowe et al. inferred that simply ceasing to stock trout in the Lakes was unlikely to lead to the recovery of the DLG population, until the other limiting factors on adult survival can also be managed. For example, other faunistic changes have also taken place in the Kai Iwi Lakes, and in particular another exotic fish, *Gambusia affinis*, was introduced between 1970 and 1973 at a similar time to the initial precipitous decline in DLG numbers (Anon 1973).

4.2 Gambusia

The presence of *Gambusia affinis* was first recorded in the Lakes in 1973, when they were observed in the channel connecting Lake Kai Iwi and Lake Taharoa (Anon, 1973). In previous surveys of the Lakes, gambusia had not been observed (i.e., Allen and Turner 1971), and so their introduction likely occurred between 1971 and 1973. This coincides with the initial decline in DLG numbers, however, in 1971 a notable decline had already been detected and it seems unlikely gambusia played a role in this given they were either not present at this time, or in low enough numbers not to have been observed.

A number of mechanisms have been proposed through which gambusia may impact on DLG populations. Pingram (2005) found that gambusia were strongly associated with shallow (c. 0.5 m) vegetated littoral habitat, and that they were strictly limited to the littoral zone, unlike other fish in Lake Waikare. Temperature preference probably plays a role in this habitat use, as the natural occurrence of gambusia is restricted to locations with summer water temperatures of 12 – 29 ºC (Froese and Pauly 2007, cited in Rowe et al. 2008). Vegetation is important for both DLG and gambusia as it provides higher prey abundance, while also providing cover from predation (Pingram 2005b). For DLG this vegetation cover on the edge of the littoral zone could be important for avoiding trout predation, as trout inhabit the open waters of the Lakes. Pingram noted that DLG were rarely observed in vegetated littoral habitat when gambusia were in high densities there.

As previously noted in Section 3.2, DLG rely on the littoral habitat for parts of their life history, and in particular they probably rely on the vegetated littoral zone for spawning. Assuming a similar egg development period to that of inanga, Pingram noted a significant overlap between the period of peak gambusia numbers, and the likely spawning period of DLG (Pingram 2005b). If this is the case, the agonistic behaviour of gambusia towards DLG could have an especially large impact on access to suitable habitat during a critical period when DLG are spawning. The assumption of a similar egg development rate has been criticised, however, as has the conclusion that the main mechanism of influence of gambusia on the DLG population is through exclusion from spawning habitat (Rowe 2016). In addition, Pingram found no significant difference between the diet of DLG and gambusia in Lake Waikare, so the two species may compete for food. Therefore, gambusia probably have a negative impact on DLG through direct competition for both food and habitat. Gambusia predation on fish larvae has been noted experimentally, as has aggression towards adult fish (Ling 2004). In the Kai Iwi Lakes, gambusia have been observed attacking adult DLG, and adult DLG have also been observed dead and dying with injuries consistent with gambusia attacks such as nipped fins and damaged eyes (Rowe 1998).

The trial cessation of trout stocking in Lake Waikare in the late 1990s was curtailed due to an increase in gambusia numbers (Rowe et al. 1999, Rowe 2002). This increase coincided with an increase in the abundance of juvenile DLG (Rowe 2002, 2016), but no increase in adult DLG abundance (Rowe 2002). Rowe (2016) therefore concludes that the main threat of gambusia relates to aggression, out-competing adult DLG for food. As a counterpoint to this, however, Pingram (2009) notes that at times gambusia and DLG have been observed in the vegetated littoral zone without aggression from gambusia towards DLG.

At the time of the trout removal trials, trout predation on gambusia was posited as an explanation for the increase in gambusia numbers, however a subsequent survey in August 2004 found no gambusia in trout stomachs in the Lakes (Pingram 2005b), and so this explanation seems less likely as a result. Nonetheless, CPUE data for March 1997 and 1998 indicated that gambusia were more abundant in Lake Waikare than previously, and were also more abundant in Lake Waikare than in Lake Taharoa, where trout continued to be stocked. The increase in gambusia numbers in Lake Waikare was well outside the inter-annual population variability seen during the previous four years of the trial. These results were interpreted as being suggestive of some mechanism of control of trout over the size of the gambusia population. Rowe (2016) posits that trout could prey on gambusia except for the tendency of gambusia to remain in vegetated habitat, thus evading capture. Citing observations of gambusia in unvegetated areas of Lake Kai Iwi, which contains none or very few trout, he concluded that the presence of trout in Lakes Waikare and Taharoa restricts gambusia to vegetated littoral habitats rather than limnetic parts of the Lakes, a process called interactive segregation. Rowe concludes that this keeps gambusia numbers lower than they would be in the absence of trout, thus lessening their impact on DLG numbers. Rowe and Pingram agree that access to non-vegetated littoral habitat likely mediates the impact of gambusia on the size of the DLG population, Pingram (2005b) noted that the uniformity of the littoral zone of Lake Kai Iwi (i.e., over 80% vegetated) may have increased the severity of the negative effects of Gambusia on DLG, potentially preventing DLG from withstanding trout predation and leading to its subsequent extinction from the lake. The persistence of DLG in Lakes Taharoa and Waikare could, therefore, be due to the patchy occurrence of littoral vegetation (i.e., not a completely vegetated or un-vegetated shoreline.

4.3 Other influences on abundance of DLG in the Kai Iwi Lakes

In addition to interactions between DLG, trout and gambusia there are a number of other factors that have been noted as influential or probably influential on DLG population numbers.

In a study of DLG and dwarf inanga, Rowe and Chisnall (1995) noted a number of factors which varied between lakes with a high abundance of dwarf inanga and those with low abundance. Emergent vegetation was found to dominate the littoral zone in lakes where dwarf inanga were abundant, and is therefore likely important for the success of the species. However, the abundance of emergent vegetation was also high in two lakes where dwarf inanga were rare, so it is not the sole factor which can limit population size. Vegetation type may also play a role, as the submerged characean plants varied between high and low abundance lakes also, with *Chara globularis* present in those with high abundance, whereas *Chara fibrosa* was present in those with low abundance. Vegetation factors likely effect abundance through their influence on spawning, however, Rowe and Chisnall note that the parent taxon, inanga, spawns on a wide range of vegetation types and therefore vegetation type is unlikely to be a limiting factor. Lakes with high fish abundance were also less acidic than those with low abundance, and had higher concentrations of silica, calcium and magnesium, and total alkalinity, and lower levels of chloride (Rowe and Chisnall 1995). The authors note that acidic conditions may negatively affect both adult galaxiids and egg and larval stages. However, they note that for this to be a significant influence, lakes where dwarf inanga were rare must have become more acidic within the last 50 years, which seems unlikely. The variations in chemical composition of the lakes may have indirect effects on fish densities through effects on planktonic species composition. In contrast to chemical composition, lake morphometry was found to have no effect on abundance. Many of the lakes in which dwarf inanga were rare contained large eels which are piscivorous, but Rowe et al. (1999) later noted that eels in the Kai Iwi Lakes are unlikely to have a significant effect on DLG populations because of their relatively low numbers. It is worth noting, however, that all of the lakes in which DLG were rare contained some fish species likely to prey on or compete with DLG, either trout, gambusia, eels, or a combination, whereas the common bully was the only other fish present in lakes where DLG were common.

Rowe and Chisnall (1995) noted that there were too few data to link abundance to water level fluctuations, commenting however that water level fluctuations may be important if spawning behaviour is similar to that of inanga. Pingram (2009) noted that larvae were often observed after a month or months of higher than average rainfall and suggested investigating the relationship between rainfall and lake water levels to look at how lake water levels vary in response to rainfall for the two lakes and to establish what impact this may have on spawning of DLG. Pingram also speculated that a combination of any rainfall and a full moon may provide a trigger for spawning.

5 Discussion

The DLG has been recognised as an evolutionary significant unit stemming from *G. maculatus* and, therefore, it is important that the population in the Kai Iwi Lakes is satisfactorily managed. Early observations of the Kai Iwi Lakes show that the DLG populations declined rapidly from the late 1960s. Surveys from the 1990s and more recent surveys undertaken by Pingram and the Department of Conservation suggest that the population is now small and has high inter-annual variability. These factors place DLG at a high risk of extinction.

It is clear that trout predation negatively affects DLG abundance. However, the difference in abundance of DLG and dwarf inanga between lakes with similar trout stocking rates suggests that other factors have also contributed to the population decline. The only study to explicitly investigate the impact of ceasing trout stocking did not demonstrate that a reduction in trout abundance would definitely lead to an increase in DLG numbers. However, the high inter-annual variability in DLG population numbers made demonstrating a rebound difficult over the course of just a few years.

It is also clear that gambusia have a negative impact on DLG abundance as they compete with DLG for both food and habitat. They have also been observed to be aggressive towards DLG and are likely to have killed individuals. The debate lies in the relative influence of trout and gambusia on DLG abundance. Rowe (2002, 2016) contended that gambusia played a larger role in the decline of DLG than trout. There is also contention over the impact of trout on gambusia population numbers and, therefore, on the impact of gambusia on DLG. During the trout stocking cessation trials an increase in the gambusia population was observed. Rowe (1999) attributed this increase in gambusia to a causative relationship from the absence/reduction of trout. However, there is no documented predatory interaction between trout and gambusia in these lakes. There is a possibility that the presence of trout leads to interactive segregation, which restricts gambusia to the shallow littoral zone, thus allowing adult DLG to more easily avoid aggression from gambusia. This interaction remains theoretical, and as yet there is little empirical evidence for it. If this is the case, however, and if interactive segregation is occurring in Lakes Waikare and Taharoa, then the removal of trout could lead to an increase in gambusia numbers and a concomitant decline in the DLG population due to increased competition for food and habitat.

Cessation of trout stocking in the Lakes would undoubtedly remove a predator and a negative influence on the DLG population. As a single management measure, however, it is not clear whether cessation of trout stocking would lead to the recovery of the DLG population. If the trials of the late 1990s are any indication, the population may not rebound without management of other factors that may be limiting abundance. Given that these trials are the only direct indication of the impact of trout removal on the DLG population in the history of trout stocking of the Lakes, they are the best evidence of the effectiveness of trout removal as a management measure. Nevertheless, these trials were short-lived and the inter-annual population variability confounds interpretation of the results.

Pingram (2005b) notes that “The decline or extinction of threatened species is often influenced by negative impacts from several competitors or predators”. So seems to be the case with DLG. Both trout and gambusia appear to have a significant negative impact on the population of DLG. Management of the Lakes for conservation of DLG would ideally include the eradication of both trout and gambusia. Gambusia, are however, far more difficult to eradicate than trout and a piscicide such as rotenone is unsuitable because of the negative impact on other fish fauna in the Lakes and its practical application in lakes with a sand substrate.

Despite numerous studies on DLG and dwarf inanga there are still many gaps in our understanding of this species which provide an impediment to effective management. In addition to making conservative management decisions now it is important to address these knowledge gaps to improve the quality of future management decisions. Understanding of the spawning ecology of DLG remains limited and theories about the influences on timing of spawning and the size of the larval cohort require further investigation. Likewise, the factors affecting survivorship from larvae to the adult stage have only been theorized about. The exact nature of the interactions between trout, gambusia and DLG are also uncertain, as theories about the role of trout in reducing the impacts of gambusia on DLG require more rigorous testing. Therefore, the monitoring programs described in the following section have been designed to help address these knowledge gaps and thus improve the ability of Northland Regional Council to make well-informed management decisions for the conservation of DLG.

6 Recommendations for a long-term fish monitoring plan for the Lakes

In recommending a plan for long-term fish monitoring in the Lakes, consideration has been given to previous monitoring efforts. In particular, these prior monitoring efforts have established which methods are most effective for monitoring numbers of the various fishes found in the Lakes. A review of these monitoring efforts is given before a monitoring plan is described.

6.1 Previous monitoring efforts

Visual surveys have been the most extensively used and a successful monitoring method for DLG. Recent monitoring of the status of DLG undertaken by DOC from 2005 – 2012 utilised night-time visual surveys (Department of Conservation 2007). They targeted sandy beach habitats, and completed surveys every 3 months throughout the year. They counted DLG in 3 size classes – juvenile (< 25 mm), sub-adult (25 – 60 mm), adult (> 60 mm). Pingram (2005b) used both night (at least 1 hour after dark) and day (early – mid-afternoon) visual surveys of the littoral zone of Lake Waikare to estimate density (fish per m^2), splitting counts of fish by size class (juvenile or adult). Surveys were conducted approximately monthly over the course of 14 months, and night surveys detected notably more DLG than day surveys (82.1% of the total count was observed at night). He concluded that estimates of DLG were more reliable at night in un-vegetated habitats.

Snorkel surveys have been undertaken on several occasions, once in each of 2000 and 2001, 5 times in 2003, and during early 2004 (Pingram 2009). Snorkelling surveys were additionally used in 2008 to estimate the total population of DLG in Lake Waikare (Department of Conservation 2008b). However, whilst snorkelling surveys are effective at locating DLG and observing shoaling behaviour and interactions with other species, they are resource intensive compared with other survey methods and are more difficult to undertake in Lake Taharoa as some sites require boat access (Pingram pers. comm. 2016).

Rowe and Chisnall (1995) found nocturnal fyke netting to be most useful method for determining the relative abundance of dwarf inanga in Lake Kanono. Rowe has also caught dwarf inanga in Lake Rototoa using G-minnow traps, allowing an average CPUE to be determined (Rowe pers. comm. 2017).

A number of other sampling protocols have been tested and ultimately found unhelpful for sampling DLG. Population monitoring using acoustic surveys was concluded by Rowe and Chisnall (1995) to only be useful for determining the presence of schools of adult dwarf inanga in deeper lakes during daylight. They also noted the limited usefulness of beach seining due to the frequent absence of DLG in seinable areas (i.e., shallow shores with no obstacles). Purse-seining was useful for detecting the post-larval planktonic stage of DLG when present (Rowe and Chisnall 1995). However, the larvae do not survive this sampling method, which is a serious consideration for a threatened species. Kilwell traps baited with Vegemite were tested during a survey of DLG in 2008 conducted by DOC, however were unsuccessful, failing to capture even a single DLG (Department of Conservation 2008b).

For monitoring other species in the Lakes Rowe and Chisnall (1995) used a combination of gill netting, windermere traps and baited fyke netting. Pingram (2005b) used minnow traps to determine CPUE for common bully and gambusia.

6.2 Recommended long term monitoring

Under the New Zealand Threat Classification System DLG is listed as "At risk – Naturally Uncommon". Given the objectives of the Northland Regional Policy statement to reduce the risk status of at risk species, the long-term monitoring of the fish populations of the Kai Iwi Lakes should focus predominantly on understanding population dynamics of DLG. However, we recommend that monitoring should also be undertaken to understand population dynamics of other fish species present in the Lakes. In particular, given the negative impact of both trout and gambusia on DLG, monitoring efforts should seek to understand the links between fluctuations of populations of these species and the DLG population. The importance of understanding these links is increased by the current intention of the Kaipara District Council to cease trout stocking in the Lakes. Ongoing monitoring will be required to establish whether this has a positive or negative impact on DLG populations, and to review the decision if required.

Here we have recommended two levels of long-term fish monitoring for the Lakes. Resource availability will determine the level of monitoring that the Council is able to undertake, however, it should be noted that detailed monitoring will be required to provide data on which to base effective management decisions. A basic level of monitoring will highlight large scale annual changes in the DLG population and give an understanding of the variability of detection rates throughout the year, along with more confident predictions of the scale of inter-annual variability of DLG populations. However, to inform management decisions, a more detailed and focused monitoring program is required, which will give an understanding of the changes in populations of other fish within the Lakes, and additionally some environmental factors which may influence DLG population variability. This provides the strongest basis for recommending management options to protect and enhance DLG populations in the Lakes.

6.2.1 Basic – Fine-scale DLG population dynamics and inter-annual changes

The minimum level of monitoring recommended would be:

- Three-monthly surveys each year (timing based on DOC data 2005 – 2012).
- Visual nocturnal surveys according to DOC methodology.

This will provide a qualitative measure of temporal variability in abundance, and may assist in understanding the links between larvae, sub-adults and adult population dynamics. Monitoring should follow the established methodology carried out by DOC between 2005 and 2012, and therefore be undertaken in February, May-June, August and November. Continuing the visual surveys would add to the long-term dataset collected by DOC and would provide a measure of the inter-annual variability in DLG abundance. However, it should be noted that the present seven years of visual surveys do not provide a sound basis for establishing management actions to conserve the DLG. Therefore, further surveys alone will not meet the objectives set by NRC in supporting management of this unique species.

6.2.2 Detailed – Fine-scale DLG population dynamics, inter-annual changes, other species, and possible influencing factors

In order to meet conservation objectives and produce management actions to increase the abundance of DLG, we recommend carrying out additional monitoring to that previously undertaken, including:

- Three-monthly surveys each year (timing based on DOC data 2005 – 2012).
- Visual nocturnal surveys according to DOC methodology.
- Catch Per Unit Effort (CPUE) surveys of adult DLG relative abundance (nocturnal fyke netting[1]) following the methodology of Rowe (1999).
- Surveys of DLG spawning sites and monitoring of spawning success.
- Monitor trout, eel, gambusia and common bully population structure, abundance and distribution.

The addition of CPUE surveys of the adult DLG population will provide quantitative data that can be statistically interrogated along with potential influences on DLG population dynamics, including environmental factors and the abundance of other fish species. Fyke netting should be tested prior to use to ensure it does not result in undue DLG fatalities, as dwarf inanga in the Poutu Lakes have been observed dead and dying in fkye nets during surveys (A. MacDonald pers. comm. 2017). This issue was not, however, encountered by Rowe (pers. comm.). The numbers of trout in each lake should be estimated from angler returns. A formal mark-recapture approach should be considered as the basis of this. CPUE of gambusia and common bully should be monitored using gee-minnow traps following the methodology described in Pingram (2005). In addition, an annual survey of eels in the Lakes should be undertaken by setting fyke nets[1] and measuring and recording the length of all eels captured. A comparison should be undertaken of the relative abundance of DLG and each of the other fish species present in the Lakes.

In addition to three-monthly surveys of the fish fauna of the Lakes, effort should be focused on determining the timing, locations and habitat used by DLG for spawning, along with identifying potential factors limiting egg development and hatching success. A range of approaches could be utilised to locate DLG spawning sites and NIWA can advise on the most applicable method based on available resources. While this work will initially be resource intensive, once spawning sites are known they can be monitored annually at little cost and the knowledge will help to answer some of the key questions currently limiting management efforts, including how important the competition of DLG with gambusia is, which life stages it most severely affects, and the level of reproductive success of DLG.

In addition to surveys of the fish populations of the Lakes, ongoing monitoring of water levels in each lake is essential to assist in relating reproduction and peaks or troughs in DLG abundance to one of the most likely environmental correlates. It would be relatively cost-effective to install a continuously logging telemetered water level recorder at one point on each lake. During data analysis the population of DLG larvae should be compared with water level both at the time of sampling and a lag of one to 3 months. Yearly visual surveys of littoral vegetation coverage at fixed locations in each lake

[1] We recommend the use of the fyke net design suggested in the Joy et al. (2013) fishing protocols with the separate exclusion section for eels

should be undertaken to monitor changes in the extent of littoral vegetation (especially that used for spawning) and the possible relationship between this factor and the population of DLG in each lake.

Long term monitoring needs to take place over a period of at least 5 years, and possibly up to 10, to observe any trends in population while accounting for the inter-annual variability in the DLG population that has been observed to date. Given the recent decision to cease stocking of trout in the lakes, it is recommended that this timeline is taken in to consideration when determining how to effectively monitor the consequences of this management action. We strongly recommend that robust, quantitative baseline monitoring is carried out prior to ceasing trout stocking.

6.2.3 Additional Studies

While the detailed monitoring strategy recommended above will provide some of the key information required to support management of DLG in the Lakes, to effectively determine the mechanisms acting to control DLG populations in the Lakes and, therefore, the most appropriate management actions, a range of additional more targeted studies are likely to be required. NIWA can provide NRC further advice on such studies, but factors that should be considered include:

- Trout diets. How does trout diet vary through the year and between lakes with and without DLG (and gambusia)? Do they predate gambusia? Do they preferentially target DLG over other food items? Do they target particular life-stages of DLG?
- Dietary competition between DLG and gambusia. How do DLG and gambusia diets vary through the year and between lakes? To what degree do their diets overlap and are populations limited by food availability and when?
- Habitat competition between DLG and gambusia. What are the preferred habitats of DLG and gambusia and how does this vary with life-stage, in time and between lakes? To what extent do DLG and gambusia habitat preferences overlap in space and time? Do gambusia exclude DLG from preferred habitats? Does the presence of trout influence DLG and gambusia habitat use? What role does littoral zone vegetation play?
- Interactive segregation between trout and gambusia. Does the hypothesized interactive segregation between trout and gambusia exist? Under what circumstances does this operate and how does this influence DLG numbers? A controlled BACI mesocosm experiment may be the most suitable approach for studying this.

Given the recent decision to proceed with ceasing trout stocking in the Lakes, it is also recommended that careful consideration be given to how this is enacted. Strong consideration should be given to how the consequences of this action can be measured, what monitoring is required and the timelines and sampling effort necessary for adequately characterising the consequences. It also offers the opportunity to test certain hypotheses about the interactive effects between the species if undertaken in a considered way. For example, does cessation of stocking in Taharoa result in the same responses in DLG and gambusia to the earlier trial in Waikare?

6.2.4 Coordination of effort

The recommended monitoring methods are generally aligned with the methods that the Department of Conservation has used recently for monitoring changes in the population of DLG in the Kai Iwi Lakes. Consistency of methods is recommended in order to maximise the comparability of data collected by Northland Regional Council and Department of Conservation. In the first instance, this will help establish the current population status of DLG with reference to the most recently available data.

In addition to adopting the methods used by DOC for monitoring the DLG population of the Lakes, it is also recommended that where possible future monitoring of fish stocks in the Lakes includes coordination between NRC and DOC. If the DOC monitoring program is resumed, it would be advisable that NRC not duplicate this monitoring, but instead establish a data-sharing arrangement with DOC, and continue to collect complementary data such as population surveys of other species in the Lakes, and related environmental variables.

As DLG is a threatened species, interested stakeholders may also support Masters or PhD projects to carry out the investigations focused on understanding the reproductive and general ecology of the species.

7 Conclusions

As has been previously noted, the isolation of the Kai Iwi Lakes means that conservation of DLG necessitates maintaining large populations in the Lakes. The extirpation of DLG from Lake Kai Iwi demonstrates the ease with which each lake population could be wiped out. The limited understanding of the effects of environmental factors and interactions between DLG, trout and gambusia, on the abundance of DLG will continue to hamper conservation efforts until it is addressed. It is recommended that ongoing detailed monitoring of the DLG population and of potential factors influencing population fluctuations be investigated. The monitoring program should include three-monthly catch per unit effort surveys of gambusia and common bully, both visual and quantitative surveys of DLG, yearly estimates of the trout population from angler returns, an annual eel survey, locating and monitoring DLG spawning sites, and monitoring of water levels and extent of littoral spawning vegetation in the Lakes. Overall, it is important the conservation efforts continue, and that factors influencing population dynamics of DLG continue to be studied and evidence used to inform management decisions.

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