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Lake Wainamu and Lake Kawaupaku: Lake Condition in 2007

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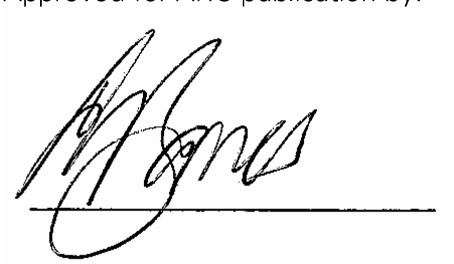

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Lake Wainamu and Lake Kawaupaku: Lake Condition in 2007

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Contents

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1 Executive Summary

Auckland Regional Council (ARC) contracted NIWA to survey the submerged vegetation of Lakes Wainamu and Kawaupaku using the LakeSPI method. Assessments were made in November 2007 and compared to earlier surveys to identify recent trends in lake condition. Estimates of the extent and biomass of the submerged weed *Egeria densa* (egeria) were also made to guide lake management initiatives including the preparation of ARC's application to stock grass carp in Lake Wainamu.

This report describes the current submerged vegetation of the lakes, LakeSPI scores, and compares these with the results of earlier investigations. The current status of egeria is discussed within a weed management context.

Both lakes were dominated by egeria to depths of 5 to 6 m depth and weed beds were surface reaching within the shallower portion of their depth range. Egeria in Lake Wainamu had increased substantially since a 2005 assessment (de Winton et al. 2005). Estimates suggest 2.7 ha of Lake Wainamu is occupied by egeria at a lake biomass of 22 - 27 tonne dry weight, and 1.45 ha of Lake Kawaupaku at 11 to 14 tonne dry weight.

The current low LakeSPI scores of 16% for Lake Wainamu and 10% for Lake Kawaupaku reflect the high impact of egeria and corresponding low representation of native plants. By contrast, historical vegetation surveys showed the lakes to score 60 - 70% prior to invasion by egeria. Scores for Lake Wainamu have further decreased since 2005. The vegetation of both lakes is considered unstable, and at moderate to high risk of collapse and further reduction in lake condition likely.

We recommend the use of grass carp to eradicate egeria from the lake system with the aim of re-establishing a beneficial native vegetation as present in 1991. Stocking of 270 fish of c. 35 cm FL are recommended for rapid total egeria control (i.e., within approximately two summers). Eradication could be achieved over a longer time-frame by using as little as 190 fish if availability and/or cost restrict stocking rates. Scuba assessment to confirm egeria removal to undetectable levels is required before attempting to reduce fish biomass (50-60%) by Prentox® baits and/or intensive netting.

Risks of not achieving the desired outcome can be mitigated by management actions, such as provision of fish exclosures to speed native plant re-establishment from seed banks. Other undesirable outcomes such as marginal rush and reed bed removal by grass carp browsing and increased turbidity may occur but are likely to be short-term (1 sumer). In our opinion the long-term benefits of ecological restoration outweigh the risks.

Lake Kawaupaku would be suited to a major restoration initiative, ultimately aimed at the eradication of coarse fish and egeria. The feasibility of a major lake drawdown to facilitate eradication should be considered. In addition we recommend an investigation into the cause of algal blooms by estimating a nutrent budget for the lake. Control of the alien giant reed, *Arundo donax* is advocated before its spread escalates.

2 Introduction

Lakes Wainamu and Kawaupaku have undergone large ecological changes associated with the invasion of the weed *Egeria densa* (egeria) and subsequent cycles in plant abundance. There is considerable community interest in the condition of the lakes and initiatives towards restoring ecological value, with future management options dependent upon identifying the direction of trends in lake condition, extent of weed invasion and the likely long-term stability of the lake ecosystems.

Auckland Regional Council (ARC) contracted NIWA to undertake a LakeSPI survey of these lakes to guide possible management initiatives. LakeSPI, a new management tool to monitor trends in lakes, uses Submerged Plant Indicators (SPI) to assess their ecological condition and to document the native and invasive character of a lake. Baseline LakeSPI and vegetation assessments at Lakes Wainamu (de Winton et al. 2005) and Kawaupaku (unpublished data) provides a comparison for the current assessments and identification of lake condition trends.

At present the management option of stocking grass carp to control egeria is being explored by ARC (Graham Surrey, pers comm.), with the intent of egeria eradication and a return to a more stable system dominated by beneficial native vegetation. This report contributes information on egeria extent and biomass to aid in management decisions.

This report describes the current submerged vegetation of the lakes, LakeSPI condition and compares these with the results of earlier investigations. The current status of egeria is discussed within a weed management context.

3 Methods

The submerged vegetation was surveyed in November 2007 at 5-6 baseline sites per lake following LakeSPI methodology (Clayton & Edwards 2006). Baseline sites were repeated as per earlier LakeSPI surveys (Lake Wainamu), or selected based on historical vegetation descriptions (Lake Kawaupaku). At each site divers recorded relevant vegetation characteristics on data sheets, including measures of diversity from the presence of key plant communities, the depth extent of vegetation and the extent of invasive weeds. Further information on LakeSPI can be found at www.lakespi.niwa.co.nz. A complete description of measured characteristics is given in the technical report and user manual at http://www.niwascience.co.nz/ncwr/tools/lakespi. Data was entered into the NIWA LakeSPI database which calculates three indices; Native Condition, Invasive Condition and the LakeSPI Index, expressed as a percentage of their maximum potential score (i.e., 100%) for each lake.

Specific measurements were made of the depth range, area inhabited, typical density and height of egeria, to estimate the biomass of the weed for consideration of management options. Estimates were based on diver observations and sonar profiles at the surveyed sites using a Lowrance LCX-15MT depth sounder/GPS/chart plotter.

4 Results

4.1 Vegetation description for Lake Wainamu

Six sites were described during the November 2007 LakeSPI survey. Egeria was recorded at all sites, forming a complete cover (>95%) from the edge of dense reed beds (0.8 - 3 m depth) down to between 4.5 and 5.5 m depth. Plant canopies were recorded to 4.2 m tall, and averaged 2 to 2.5 m in height.

Overall, four native charophyte species were recorded (Appendix 1). *Chara australis* formed patches at variable covers between 2.5 and 3.5 m at three sites and, together with other charophytes, also formed local growths adjacent to reedbeds at Sites C and D (Figure 2).

Additional Invasive species recorded from four sites included *Myriophyllum aquaticum*, found at low covers (≤25%) to depths of 4.5 m, and *Utricularia gibba* which averaged 76-95% cover to depths of 2.3 m. *Otellia ovalifolia* was infrequent being recorded at only one site.

Sonar traces show the depth distribution, height and development of the submerged vegetation, predominantly egeria (Figure 1). Surface reaching beds, shown as tall blocks within the depth range,were present at all sites. All profiles showed an increase in egeria by cover and/or depth extent over identical traces made in 2005 as reported in de Winton et al. (2005). Estimates based on current egeria depth range, together with available lake bathymetry (Rowe et al. 2005), suggest that 18% (2.7 ha) of the lake area (15 ha) supports egeria beds (Figure 2). At a typical biomass for egeria beds of 800 to 1000 g dry weight m^{-2} we estimate a total lake biomass (standing crop) of 22 to 27 tonne dry weight.

Figure 1:

Lake Wainamu sonar profiles from six LakeSPI survey sites showing depth distribution of the vegetation, predominantly egeria beds. Solid blocks are surface reaching beds and absorption of the sonar signal by dense growths also obscures the lake bed trace in places. Note horizontal distance is not to scale.

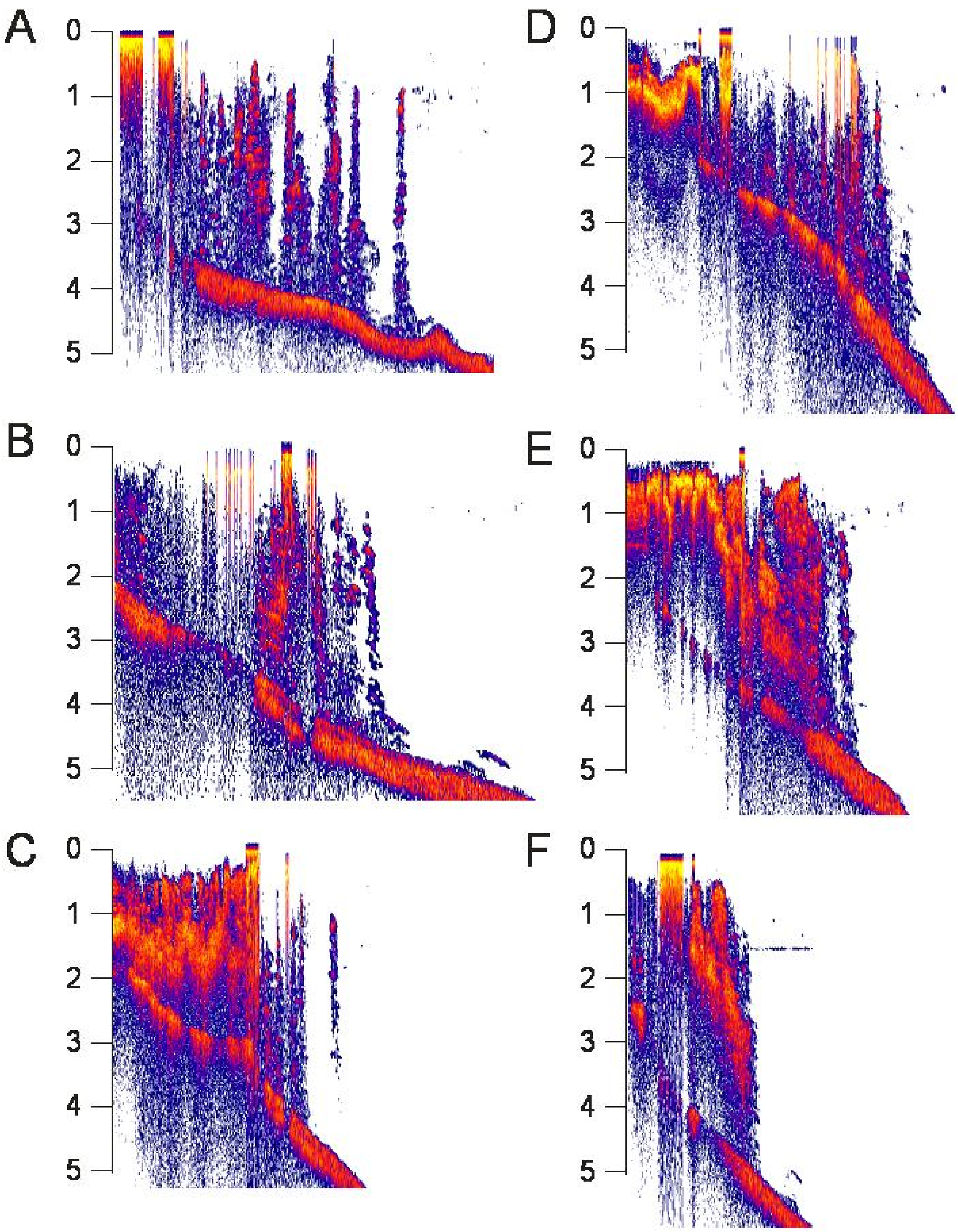
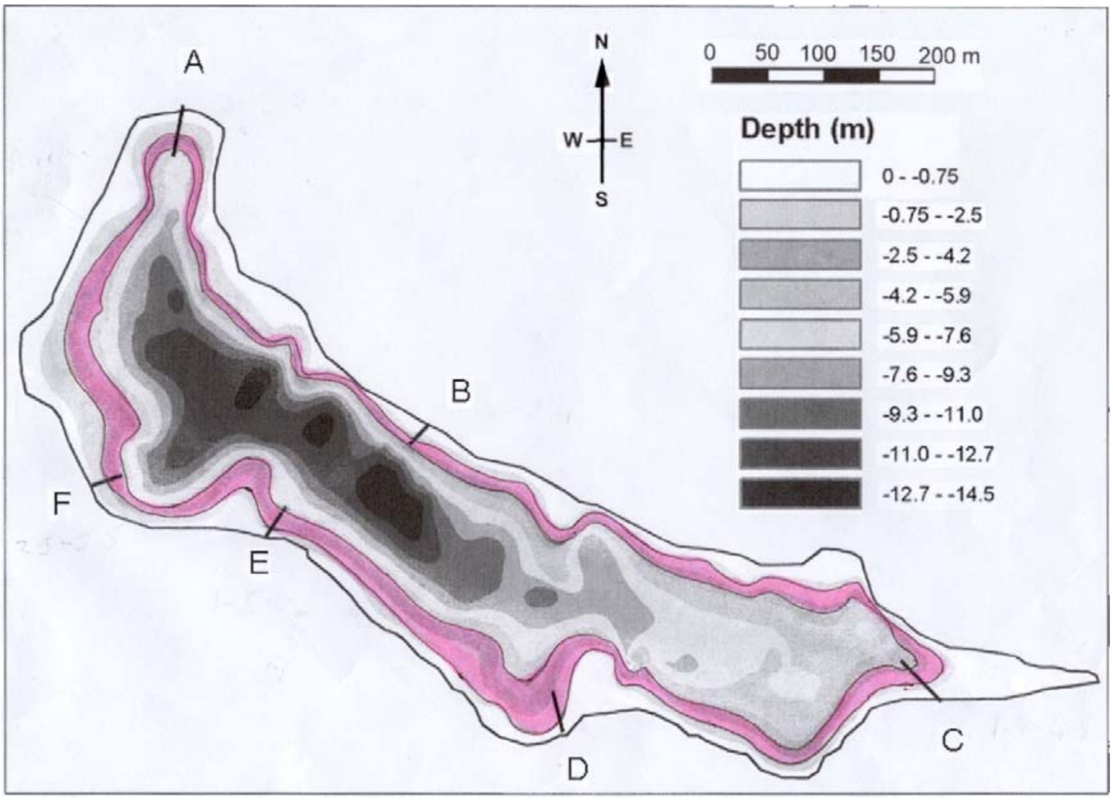


Figure 2:
Approximate distribution of egeria in Lake Wainamu, extrapolating from weed bed depth range at six sites and lake bathymetry.



The current LakeSPI assessment gave a moderately low score of 16%, driven by a very high Invasive Condition Index of 85%, with Native Condition Index depressed to 16%.

4.2 Changes in submerged vegetation of Lake Wainamu 1991 to 2007

In 1991, prior to the establishment of egeria, the submerged vegetation was predominantly native, with a zone of *Potomogeton ochreatus* and deeper charophyte meadows to 4.5 m depth (Champion 1995). The invasive weed *Utricularia gibba* was widespread but had a minimal impact. The LakeSPI score of 60% (Figure 3) reflected the predominantly native character of the lake at that time.

By 1995, egeria occupied almost all available habitat to 4 m depth and had totally replaced the native vegetation. This major change resulted in a greatly reduced LakeSPI score of 8.5%, driven by a large increase in Invasive Condition (Figure 3).

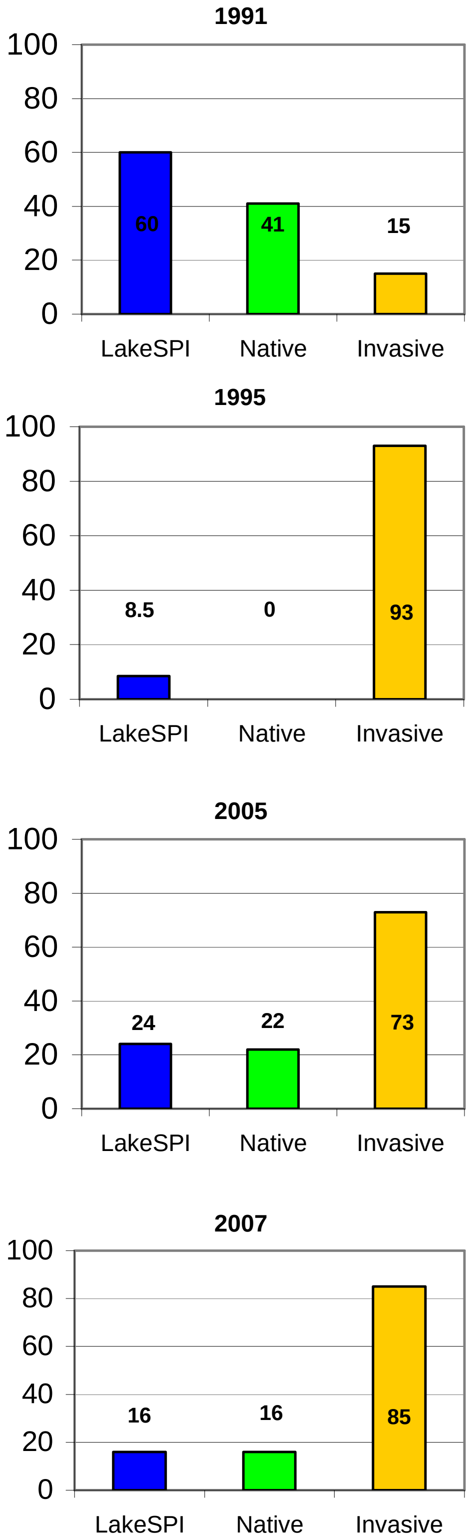
At sometime subsequent to 1995 and prior to 1999, egeria underwent a major vegetation decline (Gibbs et al. 1999). In November 2004, two out of eight sites that were sampled for seed presence had no submerged vegetation and egeria formed covers of ≤50% within depths of 3 m or less, as a narrow fringe on the outer edge of reed beds (Rowe et al. 2005). Charophytes were recorded at three sites, with dense beds at one site only.

A survey in October 2005 gave a LakeSPI score of 24% (de Winton et al. 2005) based on the restricted development of submerged vegetation and relatively high impact by invasive weeds (Figure 3), although a recent plant expansion was noted in concert with improved water quality. Egeria comprised a narrow band outside the reed beds to between 1.6 and 3.8 m depth. Beyond this, low cover (<10%) clumps of egeria were commonly encountered to a maximum of 4.8 m depth. Other weed species *U. gibba* and *Myriophyllum aquaticum* was also recorded. Charophyte beds (>75% cover) were recorded at four sites along the southern shoreline of the lake to a maximum depth of 4.7 m.

The most recent asessment in 2007 (section 4.1) shows consolidation by egeria and an extension in the depth extent of beds. *U . gibba* had also increased in cover and commonly formed a narrow band of high cover (>75%) within open growths of marginal reeds. The reduction in the LakeSPI score to 16% reflects the increase in Invasive Condition and impacts on native vegetation character. Invasive Condition Index is now close to the maximum of 93% recorded in 1995, prior to the vegetation collapse.

Figure 3:

Scores for LakeSPI Index, Native Condition Index and Invasive Condition Index for Lake Wainamu based on historical data from 1991 and 1995 and surveys in 2005 and 2007.



4.3 Vegetation description for Lake Kawaupaku

Five sites were described during the November 2007 LakeSPI survey. At this time a dense algal bloom was present in surface layers of the water column. Egeria was present at all sites. Weed beds formed an average cover of >50% (median 76-95%) from depths ≤1 m down to maximum depths of 4.7 to 6 m, although egeria was sparse in deeper water (>4 m). The canopy of beds reached a maximum of 4.2 m in height, but beds were more commonly between 2 and 2.5 m tall. Surface reaching, flowering beds were common near the lake margin (Figure 4).

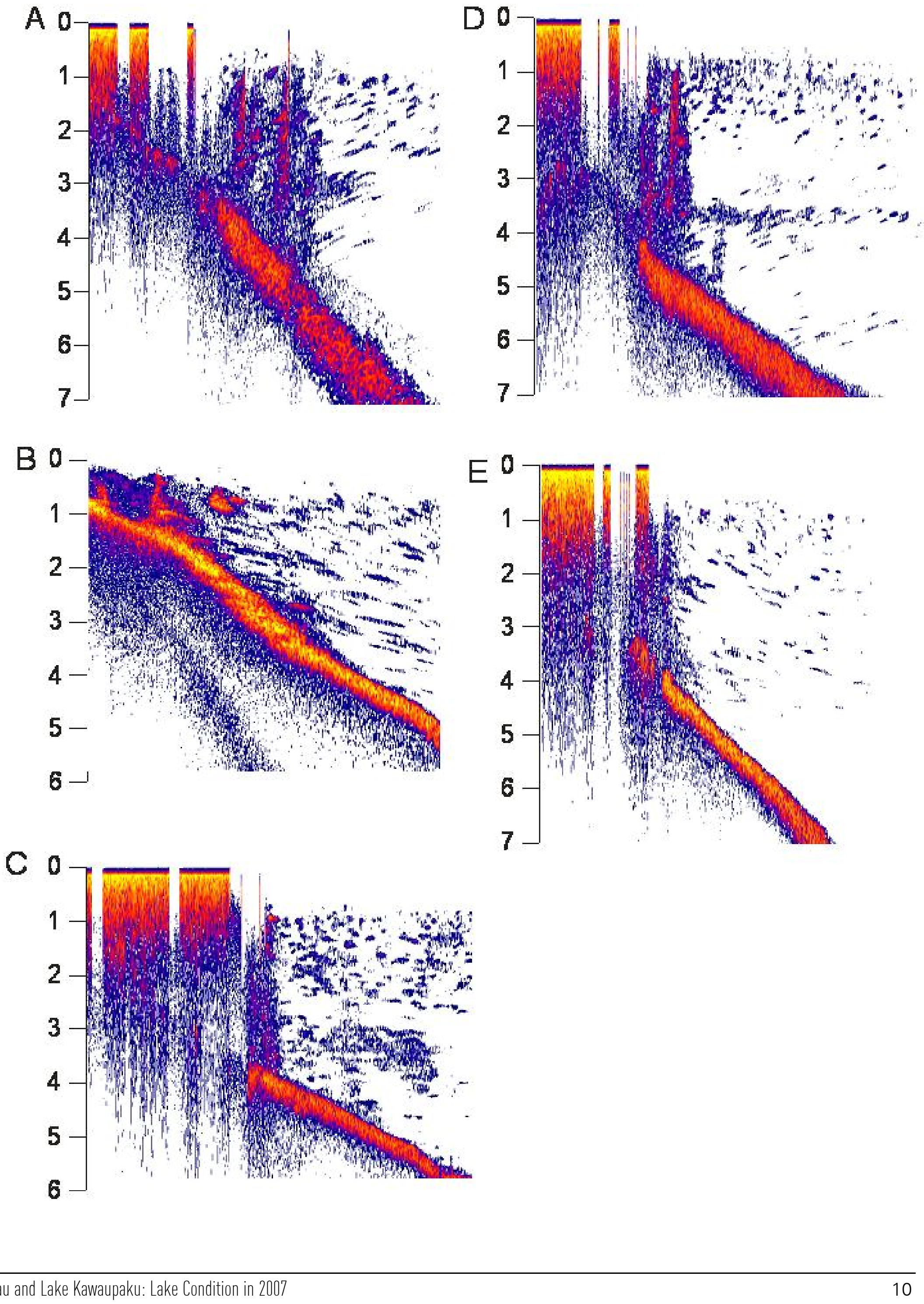
Figure 4:
The margin of Lake Kawaupaku showing a surface algal bloom and floating, flowering shoots of egeria in the foreground.

The only other recorded submerged plant was one clump of the charophyte *C. australis* observed between 3.6 and 4 m depth. No live mussels were seen although empty shells were observed at one site.

Sonar traces show the depth distribution, height and development of the submerged vegetation, predominantly egeria (Figure 5). Surface reaching beds show as solid blocks in the shallow portion of the depth range but sparse growths at the lower depth boundry are not always detected in the traces. No bathymetric data was found for this lake, but estimates of vegetated littoral distances to depths of 5 to 7 m depth in 1971 (John Clayton, unpublished data) ranged from 6 to 11 m width. Based on a mean littoral width of 8.5 m and the perimeter length of the lake at 1.7 km, we estimate egeria beds to occupy an area of 1.45 ha. At median egeria covers of 76-95% the total lake biomass (standing crop) of egeria would be 11 to 14 tonne dry weight.

Figure 5:

Lake Kawaupaku sonar profiles made at five LakeSPI survey sites showing depth distribution of the vegetation, predominantly egeria beds. Solid blocks are surface reaching beds and absorption of the sonar signal by dense growths also obscures the lake bed trace in places. Note horizontal distance is not to scale.



A current LakeSPI score of 10% results from a high Invasive Condition score of 89% and negligible remaining native character of the vegetation (Native Condition score of 3.3%).

4.4 Changes in submerged vegetation of Lake Kawaupaku 1971 to 2007

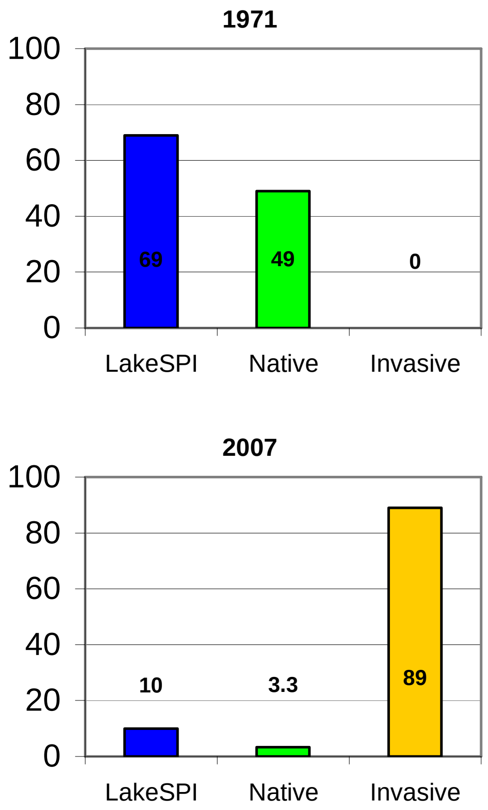
The submerged vegetation of Lake Kawaupaku was surveyed comprehensively in 1971 (John Clayton, unpublished data). At that time the lake was dominated by native pondweeds (*P. ochreatus* and *P. cheesemanii*) and charophyte beds of *C. australis* to a maximum depth of 7 m. Other submerged species recorded were *Glossostigma* sp., *Chara fibrosa* and *C. globularis*. The only adventive plant recorded was the minor weed, *O. ovalifolia*. Mussels were widespread, dense in places and extended to at least 5 m depth.

At this time the lake had a relatively high LakeSPI score of 69% (Figure 6), due to the extensive native vegetation and negligible impact by invasive weeds.

A spot dive in April 2004 (NIWA unpublished data) found replacement of native vegetation by egeria beds to a depth of 3.8 m, and an apparently recent die-off of mussels. The health of egeria plants was also noted to be poor.

The current LakeSPI score of 10% (section 4.3) documents the major change in the ecological condition of this lake, with the loss of native vegetation and its replacement by tall, monospecific beds of egeria.

Figure 6:
Scores for LakeSPI Index, Native Condition Index and Invasive Condition Index for Lake Kawaupaku based on historical data from 1971 and the survey in 2007.



5 Discussion

5.1 Current vegetation and LakeSPI

Historical and current LakeSPI assessments chart major deterioration in the condition of both Lakes Wainamu and Kawaupaku. The impact is predominantly from the invasion of egeria and almost total displacement of native submerged vegetation. There is also evidence of depth retraction in high cover vegetation in Lake Kawaupaku from 7 m to 4 to 5 m, suggesting water quality deterioration.

The possibility of another egeria decline in Lake Wainamu is considered to be moderate to high risk (de Winton et al. 2005). The lake factors that contribute to plant collapse are dense surface-reaching egeria beds developing, a poor and variable underwater light climate, and disturbance from coarse fish populations. In light of the increased biomass of egeria and observed increase in area of surface reaching beds, this remains a threat. However, the risk may have been reduced by recent and continuing reduction of coarce fish populations at the lake.

The current beds of egeria in Lake Kawaupaku are somewhat less developed than was observed in Lake Wainamu prior to the vegetation decline and loss of previously dense mussels (pobably from anoxia), suggests an unstable system vulnerable to vegetation collapse.

5.2 Weed management plan

5.2.1 Lake Wainamu

We recommend eradication of egeria from Lake Wainamu using grass carp. Previous experience of grass carp use in New Zealand shows that eradication at this site is feasible, whilst the potential for the lake to subsequently return to a predominantly native vegetated state is currently high.

The success and speed at which weed beds can be controlled and eliminated depends on the number and size of stocked fish and their subsequent growth rate. Here we review required stocking rates based on an initial biomass of fish and area of weed infestation (i.e., fish kg ha^{-1} of weed).

5.2.1.1 Grass carp stocking rates

Rowe & Schipper (1985) reviewed overseas use of grass carp for vegetation control and indicated that a minimum stocking density for grass carp to obtain total removal of vegetation overseas was 100 kg fish ha^{-1} weed.

The maximum density permitted in Texas waters is 17 fish ha^{-1}. This looks low, but assuming growth to 10 kg after about five years and no mortality, it would produce a final density of over 170 kg ha^{-1}.

Blackwell & Murphy (1996) found that an initial density of 6 kg ha^{-1} (4 fish ha^{-1}), increasing to >40 kg ha^{-1} after five years fish growth, had no effect on long term weed biomass, but they did obtain complete control in one lake with an initial density of approximately 15 kg ha^{-1} (7 fish ha^{-1}), increasing to >70 kg ha^{-1} after five years. Stocking densities of less than 100 kg ha^{-1} weed therefore can result in total control, but it can be expected to take much longer.

Weed eradication from New Zealand lakes by grass carp has been documented in Lake Parkinson and Waihi Beach Reservoir (Mitchell 1980), Lake Waingata (Rowe et al. 1999), and Lake Eland (Clayton et al. 1995).

1. A stocking density of 215 kg ha^{-1} weed (80 grass carp at 3.5 kg) resulted in total weed removal in Lake Parkinson after two summers where the initial area of weed cover was estimated to be 1.3 ha. This initial stocking density exceeded Rowe & Schipper's (1985) recommendation, but the intention was to ensure quick and total control. Restablishment by native macrophytes was documented within five years of removal of the fish (Tanner et al. 1990).

2. A stocking density of 187 kg ha^{-1} weed (100 grass carp at around 2.15 kg) was used to remove all weed in the Waihi Beach Reservoir which contained approximately 1.15 ha weed. This stocking density resulted in total control after two summers.

3. A theoretical stocking density of 100 kg ha^{-1} weed was estimated to ensure fast control of weed in Lake Waingata but at 7 ha of weed cover, stocking of the required fish biomass (700 kg grass carp) was not possible. Stocking was therefore preceeded by partial chemical control and 168 grass carp (initial biomass 250 kg) were then introduced. Assuming 50% reduction of weed biomass by chemical control, the effective initial stocking rate was 250 kg fish per 3.5 ha of weed (or about 70 kg ha^{-1} weed). Assuming 20% fish mortality over the first two years and a doubling of weight for the remaining fish, the biomass of fish would have increased to at least 400kg. The remaining weed cover would have been less than 2 ha after two years, giving an effective rate of about 200 kg ha^{-1} weed and hence more than enough to ensure total control after 3-4 years. Grass carp density was partially reduced in 1999, but the remaining fish supressed all macrophytes until at least 2006.Natural mortality is now expected to have occurred to the point where native plants are recovering.

4. A stocking density of 392 kg ha^{-1} weed (392 fish of approximately 1 kg) in Lake Elands removed 1 ha of weed cover within 2.5 years.

For Lake Wainamu a target grass carp density of 100kg ha^{-1} (i.e., 270 fish at 1 kg) is recommended for the weed coverage of 2.7 ha. This estimate is based on a fish size of c. 35 cm FL, as at this size fish are efficient grazers and are too large for predation by shags. If the recommended density is not feasible (fish availability or cost) a minimum stocking rate of 70 kg fish ha^{-1} (189 fish) would be required.

5.2.1.2 Release of carp, monitoring and recapture

Depending on availability of fish of the recommended size, we advocate that stocking take place before the 08/09 summer. It is envisaged that fish at the target stocking rate would remove 80% of weed biomass in the first summer and 100% by the end of the second summer, but 100% control may take 3-4 summers at a lower fish density. Eradicatation of the weed beds in this lake as soon and as quickly as possible, with subsequent reduction of fish biomass, will minimise the duration of any increase in turbidity.

In terms of monitoring the outcome of grass carp grazing, simple monitoring of weed presence using grapnel drags and/or sonar traces at c. five sites would be sufficient to confirm reductions in biomass. More than one site is advocated as fish may preferentially graze some areas before others. More critically, a scuba diver based assessment of weed presence after the second summer is needed to confirm removal of egeria to undetectable levels. At this stage even a low browsing pressure by fish would be capable of removing any recovering plants, so the majority of fish could be removed.

Once egeria is undetected during the scuba monitoring, grass carp removal can proceed as quickly as possible with the aim of removing 50-60% of stocked fish. One method to use is the rotonone bait Prentox®. This requires a period for fish to acustom to feeding on palatable baits at a feeding station before the rotenone impregnated baits are substituted. An automated feeding station that releases floating pellets within a feeding ring has been used previously and would be available for hirage. After the initial introduction of the rotenone baits the fish quickly become aware of the danger so it is imperative to achieve a maximum kill in the first attempt. Removal using gill nets is another option, with good success in both Lake Parkinson (authors observations) and Lake Elands (J.S. Clayton, NIWA, pers comm.) achieved by driving fish towards the nets using motor boats. Nevertheless, Lake Wainamu has considerable deep water refuges that cannot be netted and the fish are generally considered 'net-shy'. Conversely, they may be suceptable to nets placed in deep water where light levels are lower. Community involvement by line fishing or bow hunting could also be encouraged, however, there is little control of outcomes or record keeping.

We recommend stocked fish also be tagged with PIT tags for individual identification. Tags cost $10-20, and could enable monitoring of grass carp population size, natural mortality losses and the outcome of removal efforts such as Prentox® poisoning. The addition of PIT reader equipment to the automated feeding station would record the I.D. number of individual fish as they approach the feeding ring, within a reading distance of c. 1 m. Monitoring at a frequency of once per year should provide estimates of the grass carp population remaining.

5.2.1.3 Prevention of emigration

Grass carp would attempt to emigrate from the lake via the stream outlet, especially at times of high (flood) flows. A barrier screen would therefore be required on the outlet stream, however the stream bed comprises mobile sand and structures would be susceptile to breach or by-pass in storm events. It is therefore envisaged that a fish berrier would be required, comprising a weir structure overtopped with a vertical screen of steel rods spaced with 30-35 mm gaps (depending on minimum size of fish). Maintenance of this screen is required to prevent weed fragments and debris building up and clogging it. Without maintenance, fouling could lead to a water level rise and overtopping of the weir with subsequent wash-out and barrier failure.

A mesh barrier net (extending from the lake surface to the lake bottom) deployed within the lake where it narrows before discharging to the outlet could provide a weed boom and offset the need for daily screen maintenance and reduce the risk of a blow-out. A barrier net has the advantage of giving a wide area for water movement and allows weed or reed debris to be deflected without the barrier being dislodged or breached, but the net may still require periodic clearing for an initial period before most macrophytes (and rush beds) are removed from the lake. The net would also act as a secondary barrier for fish.Once most weed and rushes are removed from the lake (e.g., after the 1st summer) the net can be removed to allow fish access to any plants between the structures.

5.2.1.4 Risks associated with the recommended action

The local community have concerns that lake vegetation removal by grass carp may trigger a return to a more turbid system, as experianced when the lake was de-vegetated (late 1990's to 2005). While some short-term increases in turbidity are likely because the beneficial influence of vegetation presence is reduced, on-going high levels of turbidity are not an inevitable outcome of vegetation removal. Firstly, the lake is much deeper than typical New Zealand waterbodies that have switched to a persistant de-vegetated and turbid state (e.g., Lakes Omapere, Waikare) and is not so vulnerable to wind/wave driven re-suspension of bottom sediments. However, turbidity can be increased by subsidence and bank slippage irrespective of weed presence. Secondly, the water quality improvement seen with previous fish control works shows the system is amenable to management and can be shifted to a clearer water state as long as fish control is maintained. Lastly, increased turbidity is likely with a future egeria collapse if management actions are not undertaken. A stocking strategy for rapid weed bed eradication and early removal of grass carp would limit any period of increased turbidity.

Previous assessments showed a widespread native seed bank presence in the lake and a good potential for germination response (Rowe et al. 2005). Subsequent development of native charophyte beds was observed (de Winton et al. 2005), before their exclusion by competitive egeria weed beds. Long-lived native seed banks will persist within the lake and may have been replenished when charophyte beds briefly recovered, so there remains a high liklihood of native vegetation recovery.

Removal of grass carp can prove difficult. In the event that sufficient grass carp cannot be removed, they are likely to have a lifespan of c. 15-20 years. Even low grazing pressure by remnant grass carp could prevent native plant re-establishment unless widespread germination occurs from seed reserves, that exceeds grazing removal rates. To ensure native vegetation recovery can occur quickly it may be neccessary to construct fish exclosures and place these in some areas to allow plant establishment to a level where plant biomass production exceeds removal by grazing.

In the event of grass carp escape from the lake, there is little scope for impacts as the linked Waitakere River system has an extensive vegetated area, thereby diluting the browsing effect any fish would have. Negligible impacts would be expected in this area even if all the grass carp recommended for Lake Wainamu were to escape.

We would not expect grass carp removal of marginal plants until the more palatable submerged plants were largely removed. Given the area and high density of the rushes/reeds at the lake margin, it is not certain what level of impact grass carp would have. Some break-up and release of floating rafts of plants may be possible. However, clearance of outer rush/reed beds where egeria fragments may persist will improve chances of early weed eradication. Grass carp are also capable of eradicating the weed *Myriophyllum aquaticum*, but the alien bladderwort, *Utricularia gibba*, could be re-introduced by wildfowl due to its fine, entangling growth. The latter is widespread in the Waitakere wetland and possibly sets seed.

The risk of re-introduction of egeria is considered low. The weed is not transported by wildfowl, nor is a re-invasion source present in upstream catchment watercourses. Without good vehicle access or a formed boat ramp, boat traffic to Lake Wainamu is restricted to small craft with a low likelihood of weed transfer. Further introductions associated with coarse fish liberations are also less likely following public education campaigns on the impacts of coarse fish. Signage at access points to the lake may further reduce the risk of misguided weed releases.

5.2.1.5 Conclusion

By using grass carp it is feasible to completely remove egeria weed beds from Lake Wainamu and ultimately return to a low-growing native vegetation, as was present in 1991 and earlier. The risks to the success of this strategy and the likelihood of other undesirable outcomes are low and in many cases could be mitigated by further actions. In our opinion the long-term benefits of ecological restoration outweigh any of the short-term risks to the system.

5.2.2 Lake Kawaupaku

This lake is privately owned but would be well suited to a major restoration initiative with the assistance of research agencies and local authorities. The relatively natural catchment, without large agricultural inputs, means there is considerable scope for returning the lake to its prior condition. However, the lake is now severely degraded and any restoration initiative will need to be extreme to reverse this degredation. The potential exists for a major draw down of the lake (e.g., by siphon) and treatment of residual waters with herbicide and piscicide to eradicate coarse fish and egeria. An assessment of the feasibility of such a drawdown would require knowledge of the local hydrology and water table levels. Once eradicated, the risk of re-introduction of weed or coarse fish would be low.

An assessment of nutrient sources as the cause of destabilising algal blooms should be made, towards identifying possible management actions. For example, the contribution of nutrients by roosting shag colonies (*Phalacrocorax s*p.) in trees adjacent to the lake and other likely sources in the catchment or lake could be estimated.

We recommend control of alien giant reed, *Arundo donax*, as its spread could impact on native marginal vegetation in time. Control should be achieved with applications of the herbicide Gallant in spring and/or autumn.

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7 Appendix 1

Species list from the November 2007 survey of Lake Wainamu, showing overall depth range, heights (maximum and average) and covers (maximum and median average).

Species	Number of sites	Depth range (m)	Average height (m)	Maximum height (m)	Maximum cover	Median average cover
Azolla pinnata	1	0 - 0		0.0	6	5
Baumea articulata	6	0 - 1	2.0	3.2	6	5
Chara australis	5	1 - 4	0.5	1.5	6	2
Chara fibrosa	1	2 - 2.2	0.1	0.2	2	1
Chara globularis	1	2 - 2.2	0.6	0.6	2	1
Carex sp.	1	0 - 0.2	0.4	0.4	2	1
Eleocharis acuta	1	0 - 0.2	0.4	0.4	3	2
Egeria densa	6	0.8 - 5.5	2.4	4.2	6	6
Eleocharis sphacelata	6	0 - 3	2.4	3.5	4	3
Galium palustre	1	0 - 0.2	0.2	0.2	2	1
Isachne globosa	2	0 - 0.3	0.4	0.4	5	4/5
Ludwigia peploides	2	0 - 2	0.2	0.4	2	1
Myriophyllum aquaticum	4	0 - 4.5	1.1	4.5	2	1
Nitella aff. *cristata*	2	1 - 2.7	0.5	0.6	6	2/4
Nitella pseudoflabellata	1	2 - 2.2	0.4	0.4	1	
Otellia ovalifolia	1	2 - 2.1	0.5	0.5	1	1
Landoltia punctata	1	0 - 0		0.0	1	1
Schoenoplectus tabernaemontani	1	0 - 0.3	1.8	1.8	2	2
Typha orientalis	4	0 - 2.5	2.4	3.0	4	2
Utricularia gibba	4	0 - 2.3		0.0	6	5

Species list from the November 2007 survey of Lake Kawaupaku, showing overall depth range, heights (maximum and average) and covers (maximum and median average).

Species	**Number of sites**	**Depth range (m)**	**Average height (m)**	**Maximum height (m)**	**Maximum cover**	**Median average cover**
Baumea articulata	2	0 - 1.5	1.8	2.2	5	4/5
Baumea arthrophylla	1	0 - 0.8	1.5	1.8	3	3
Chara australis	1	3.6 - 4	0.1	0.2	2	2
Carex sp.	2	0 - 0.3	0.7	0.8	4	2/4
Eleocharis acuta	1	0 - 0.3	0.5	0.5	3	2
Egeria densa	5	0.3 - 6	2.4	4.2	6	5
Eleocharis sphacelata	1	0 - 0.5	2.0	2.0	3	2
Isachne globosa	1	0 - 0.2	0.4	0.4	3	3
Nasturtium officinale	1	0 - 0.4	0.3	0.3	3	3
Persicaria decipiens	2	0 - 0.3	0.3	0.4	2	1/2
Phormium tenax	2	0 - 0.4	1.4	2.5	6	4/5
Ranunculus amphitrichus	1	0.2 - 0.2	0.1	0.1	1	1
Landoltia punctata	1	0 - 0		0.0	1	1
Typha orientalis	3	0 - 1	2.1	3.5	6	3