Status of New Zealand fresh-water eel stocks and management initiatives

Don J. Jellyman


New Zealand has two main species of fresh-water eel, shortfin (*Anguilla australis*), which is shared with Southeast Australia, and the endemic longfin eel (*A. dieffenbachii*). Both species are subject to extensive commercial and customary fishing. The shortfin is the smaller and shorter lived, with typical generation times for females ranging from 15 to 30 years; generation times for longfin females are double this. The distribution and the abundance of both species have been compromised by habitat modifications, shortfins, the more lowland species, being affected by wetland loss, and longfins by weirs and dams. Although there are few concerns about the status of shortfins, there is increasing evidence of overexploitation of longfins, including reduced recruitment, reduction in catch rates, reduction in abundance and average size, and a regional reduction in the proportion of females. Eels are managed under the quota management system, although individual and regional quotas are set from catch histories because biological parameters are inadequate. Maori, New Zealand’s indigenous people, have been allocated 20% of commercial quota, with additional quota set for customary take. The annual commercial catch of eels has halved over the past decade, and is now ~700 – 800 t, shortfins comprising 66% of catches. Recent management developments have included enhancement of upstream waters with juvenile eels, consolidation of processing into fewer but larger units, setting aside of additional reserve areas to increase escapement of silver eels, increased management involvement of Maori, and development of regional management strategies.

**Keywords:** abundance, *Anguilla*, exploitation, fresh-water eels, management, Maori, quota, recruitment, status

Received 3 January 2007; accepted 25 April 2007; advance access publication 21 June 2007.

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Eel species

New Zealand has two main species of fresh-water eel, the shortfin eel (*Anguilla australis*), which is also found in southeastern Australia and at some Pacific islands, and the endemic longfin eel (*A. dieffenbachii*) (McDowall, 1990). Within the past decade, a third species, the Australian longfin eel, *A. reinhardtii*, has been found in the northern parts of the North Island of New Zealand (Jellyman et al., 1996). Although it appears to be a reasonably frequent immigrant, this last species is not a significant component of New Zealand eel biomass. Like fresh-water eels worldwide, the species are assumed to be panmictic, consisting of single genetic stocks despite occupying broad geographic ranges. Shortfins from Australia and New Zealand show significant genetic homogeneity (Dijkstra and Jellyman, 1999; Smith et al., 2001), at least at the glass eel stage.

The main species frequently coexist, but the shortfin is principally a lowland species, dominating populations in lowland lakes, estuaries, and the lower reaches of rivers. It reaches a maximum size of about 1.1 m and 3 kg, compared with the 2.0 m and 25+ kg for the native longfin (Jellyman, 2003). Longfins prefer flowing water and hence are found extensively in mainstem rivers; they penetrate long distances inland and inhabit high country lakes and rivers. The two species have different habitat preferences (Jellyman et al., 2003). Although juveniles of both species prefer shallow water (<0.5 m deep), juvenile shortfins prefer slow velocities (<0.5 m s−1) and fine substrata, and juvenile longfins faster water (>0.5 m s−1) and coarse substrata. Adults of both species prefer deep, slow-moving water, but shortfins again prefer finer substrata (mud) than longfins (coarse gravel and boulders). There is experimental evidence of shortfin glass eels making specific olfactory choices about the types of waterways they invade, but longfins appear indifferent to water type, a response in keeping with their broader habitat preferences (McCleave and Jellyman, 2002).

**Customary fisheries**

Before European settlement, New Zealand’s indigenous Maori people had a highly developed fishery for fresh-water eels. In the absence of native mammals, eels were enormously important as a basic foodstuff, because they were widespread, abundant, easily caught, and capable of being preserved. As a result, Maori had an extensive knowledge of the ecology of eels, and developed effective fisheries for both species, harvesting feeding and silver eels through combinations of traps, spearing, bait fishing, and large weirs (Downes, 1918; Schmidt, 1925; Best, 1929; McDowall, 1990).

Eels feature extensively in Maori mythology, large eels often being credited as spiritual guardians of waterways (Best, 1929). Wars were sometimes fought over the rights to fish for eels in particular rivers. Maori practised various forms of management,
including imposing fishing bans on a waterway for ceremonial or conservation reasons, and seeding areas with small eels.

Although most of the present-day harvest by Maori utilizes European fishing techniques, some customary fisheries practices still operate. For example, in a small coastal lake (Lake Forsyth, 560 ha) in the South Island, migrating shortfin eels accumulate at a gravel bar separating the lake from the sea, where they are gaffed on dark nights when they enter drains dug into the gravel bar. Several hundred may be taken on a good night’s fishing (Todd, 1978).

Maori have frequently expressed concern that commercial fishing has compromised their own ability to harvest sufficient quantities of large eels for ceremonial purposes, and that such land-use practices as wetland drainage and stream clearance have led to a significant degradation of eel habitat. There is also a general desire for eel stocks to be rebuilt to pre-commercial fishing levels, although unfortunately this would seem to be impossible because of irreversible land-use changes.

**Development of the commercial fishery**

The commercial eel fishery in New Zealand commenced in the early 1960s, and grew rapidly until annual catches of 2000 t were recorded in the early 1970s. Development of the fishery can be classified into three phases: (i) an exploitation phase (1965–1980); (ii) a consolidation phase (1980–2000); and (iii) a rationalization phase (2000 on). The exploitation phase was characterized by rapid expansion of the industry, a proliferation of processing factories, and generally large export volumes of a relatively low-value product. There were few management constraints, and early concerns were more to do with the possible impact of fishing on the important recreational trout fishery than on eel stocks themselves. In the early 1990s, 23 processing factories operated (Jellyman, 1993), and there was no limit on catches or the number of commercial fishing licences issued. An initial minimum size of 150 g introduced in 1981 was increased to 220 g in 1992, in an endeavour to improve marketability and yield-per-recruit. To “cap” the escalating catches in Lake Ellesmere, then New Zealand’s single largest eel fishery, the lake was declared a “controlled fishery” in 1978, and a (maximum) total allowable catch (TAC) was set.

During the consolidation phase, Government moved to reduce the pressure on eel stocks, because there were some concerns about overexploitation. Two important constraints were the exclusion of part-time commercial fishers from the industry (1982), and a freeze (moratorium) on the issuing of new licences in 1988. Associated with the licence freeze was a voluntary agreement by the eel industry not to increase fishing effort beyond that of the late 1980s. To assist with this, a legal loophole that enabled multiple fishers to operate from a single fishing permit was closed in 1997. Towards the end of this phase, fishery managers encouraged cooperative management planning by industry and Maori, which resulted in a series of regional management plans for the South Island (Te Waka a Maui me ona Toka Mahi Tuna, 1996). These plans formed the information base required for the next phase, the entry of eels into the quota management system (QMS).

In the rationalization phase, South Island eels were introduced into the QMS in 2000, and a (maximum) TAC was set, with the commercial portion of this allocated to fishers largely on the basis of previous fishing history. The allocation of individual transferable quotas (ITQs) to fishers is considered to provide an incentive for conservation through the allocation of transferable rights to harvest in perpetuity (Batstone and Sharp, 1999). Similar to marine species, Maori received 20% of the commercial quota, and in recognition of the historical importance of eels to them, catch allocations were also made for customary purposes (another 20% of the TAC). Unfortunately, South Island quota was set for both species combined, meaning that there was and is no segregation of quota by species; quota was allocated to six regions, fishers often being permitted to fish in more than one region.

North Island eels entered the QMS in October 2004, catches again being allocated based on fishing history. In recognition that longfins were being harvested at a rate considered by fishery managers to be unsustainable, quota for that species was set at 18% less than recent commercial catches. Again, a substantial allowance was made for customary purposes (14% of TAC), and 11% for recreational eel fisheries. A recent development has been a marked reduction in the number of processing companies to two main ones, who also hold much of the quota for both islands. One of these companies is owned by Maori. In recognition that eel stocks in some regions are showing signs of significant depletion, eel fishers have sometimes voluntarily forgone opportunities to catch their annual entitlements to assist stocks to rebuild. A consequence of the entry of commercial eel fisheries into the QMS has been the loss of a considerable number of experienced commercial fishers, who have opted to sell their ITQs. For instance, there were 70–80 commercial eel fishers in the South Island before QMS introduction, but now there are only ~20. There has also been an overall reduction in commercial fishing activity, as security of quota holdings has meant that commercial fishers can fish more conservatively, often on a rotational basis if access agreements can be made with landowners.

Because of a lack of stakeholder involvement in the management of key fisheries, current Government management initiatives are in the development of Fishery Plans, whereby collaborative plans for particular species, stocks and areas can be drawn up cooperatively by fishery managers and industry stakeholder groups. Whether fresh-water eels will constitute a single national plan, or a series of regional plans, is uncertain at this stage.

**Current status of eel stocks and fisheries**

Commercial eel fishers supply a monthly catch and effort return. These data are cross-checked against monthly returns from eel processors (Licensed Fish Receivers), and any significant discrepancies between the two datasets are investigated. Reported commercial fishery catches (Figure 1) show the rapid increase in catches in the late 1960s to a peak of 2077 t in 1972, 25 years of markedly fluctuating catches, and a general decline since 1994/1995 to currently a little over 700 t (Sullivan et al., 2005). Declines in the commercial catch since 2000 are attributable to the introduction of the QMS (and attendant loss of experienced fishers), varying overseas markets, some reductions in areas available to commercial fishers, droughts, and availability of eels. Shortfins have always been the dominant species, averaging 64% of the total catch over the past 30 years. Although longfins have sometimes contributed as much as 45% of the annual catch, their proportion over recent years has consistently been about one-third of the total catch. North Island catches have always exceeded South Island catches, the relative contributions over the past 14 years being 64% and 36%, respectively.

The present South Island TAC is 539 t, of which the total allowable commercial catch (TACC) is 78%, 20% is available for customary fishing, and 2% for recreational fishing (Figure 2). The customary and recreational catches are not monitored, but on
average, just two-thirds of the TACC has been caught in any of the 5 years since it was established. For the North Island, the TAC is currently 885 t, of which 73% is the TACC, 14% is for customary fishing, 11% for recreational fishing, and the remaining 2% is in recognition of other (unspecified) sources of fishing-related mortality. The TACC for the North Island is separated by species, and in the 2004/2005 fishing year (the only year of data since North Island eels were introduced into the quota system), only 65% of the TACC for shortfins (457 t) was taken, together with 67% of the TACC (193 t) for longfins. Much of this reduction is considered to be a consequence of industry rationalization associated with entry of eels into the QMS. Today, apart from National Parks, various reserves, and a few designated non-commercial areas, most accessible waters are fished commercially.

Apart from small quantities of glass eels that can be caught for research purposes, it is not legal in New Zealand to catch or export glass eels. High overseas prices for glass eels in the 1970s stimulated experimental capture of this life stage in the Waikato River, the river with New Zealand’s largest recruitment. As much as 6 t was caught in a single year (Jellyman, 1979), although anecdotal reports indicate that such large recruitment is now infrequent. Apart from an experimental eel farm in the north of North Island (Whangarei), there is currently no intensive farming in New Zealand; trials of eel fattening (short-term, low density)
Research and management initiatives

Initial research on eels in New Zealand was prompted by concerns that they were significant predators on trout (Cairns, 1942; Burnet, 1968). An outcome of research into that subject was that the predatory pressure by eels was beneficial to the production of brown trout of a size of interest to anglers. Subsequent research then focused on understanding recruitment (Jellyman, 1977a, b), the ecology of yellow eels (Chisnall, 1989; Jellyman, 1989; Chisnall and Hayes, 1993; Broad et al., 2001), and factors associated with the onset of maturity and downstream migration (Todd, 1981a, b). With the rapid development of the commercial fishery, emphasis changed to understanding the age composition and growth rates of eels in a range of waterways (e.g. Beentjes and Chisnall, 1998), and monitoring and modelling impacts of commercial fishing (e.g. Beentjes and Bull, 2002). Recent advances now allow researchers to estimate the biomass of eels in waterways by linking eel biomass/habitat relationships to a GIS rivers database (Graynoth and Niven, 2004).

Estimates of mean age at migration were made using averaged growth rates estimated from sampling of commercial landings (Beentjes, 1999; Beentjes and Chisnall, 1998), relative to mean lengths of female silver eels of 740 mm for shortfins and 1150 mm for longfins (Jellyman and Todd, 1982). Growth rates for both species are higher in the North Island than in the South Island and result in shorter generation times (Table 1), and at migration longfins are twice as old as shortfins. These ranges in age at migration substantially exceed those of other temperate eels important in world commerce (A. anguilla, Svedang et al., 1996; A. rostrata, Oliveira and McClave, 2000; A. japonica, Tzeng et al., 2000).

Considerable effort is under way investigating the behaviour of eels approaching dams, to design appropriate means of downstream passage. To date, the use of submerged bypasses has met with some success, but during floods eels preferred to migrate over a spillway in preference to the much smaller flow provided by a bypass (Boubee and Williams, 2006). Likewise, selective opening of spillway gates can be an effective means of enhancing downstream passage (Watene et al., 2003), and predicting migration periods from rainfall events significantly reduces the loss of stored water (Boubee et al., 2001). The use of radio and acoustic telemetry continues to be very important to understanding migratory behaviour. In Lake Manapouri, where a hydro-station diverts up to 97% of the outflow, studies have indicated that approximately half the silver eels entering the lake are attracted to the power station forebay and will be killed by passage through the turbines (NIWA, unpublished data).

In the absence of fisheries for glass eels, some recruitment monitoring has been implemented. Representative locations in both the North and the South Island are electric-fished for glass eels, to obtain an index of annual recruitment (Chisnall et al., 2002; Jellyman et al., 2002). From 10 years of data, there are no clear indications of changes in abundance of either species. In addition, the annual congregation of juvenile eels (elvers) below hydrostations is now monitored through joint initiatives between the eel industry and fishery managers. Currently, up to 3 million juvenile eels are transferred upstream annually (Martin

Table 1. Estimated age of female silver eels (shortfins, for a mean length of 740 mm; longfins, for a mean length of 1150 mm) for various regions in New Zealand.

<table>
<thead>
<tr>
<th>Region</th>
<th>Shortfin numbers aged</th>
<th>Shortfin mean age</th>
<th>Longfin numbers aged</th>
<th>Longfin mean age</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Island</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Western</td>
<td>288</td>
<td>18.1</td>
<td>126</td>
<td>33.5</td>
</tr>
<tr>
<td>Eastern</td>
<td>150</td>
<td>15.3</td>
<td>25</td>
<td>27.6</td>
</tr>
<tr>
<td>Southern</td>
<td>140</td>
<td>16.4</td>
<td>123</td>
<td>29.0</td>
</tr>
<tr>
<td>South Island</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Western</td>
<td>65</td>
<td>40.2</td>
<td>151</td>
<td>63.9</td>
</tr>
<tr>
<td>Northern</td>
<td>7</td>
<td>27.9</td>
<td>9</td>
<td>54.5</td>
</tr>
<tr>
<td>Central</td>
<td>116</td>
<td>25.7</td>
<td>263</td>
<td>44.5</td>
</tr>
<tr>
<td>Southern</td>
<td>316</td>
<td>23.3</td>
<td>525</td>
<td>51.4</td>
</tr>
</tbody>
</table>

Estimated ages are derived from growth rates given by Beentjes and Chisnall (1998), and Beentjes (1999).
et al., 2005). Such ventures were initiated by industry to seed hydrolakes where resident eel stocks had become depleted through lack of recruitment. Growth rates resulting from such transplants have been impressive, with eels achieving the minimum commercial size of 220 g within 4–6 years, compared with 13–17 years in reaches downstream of dams (Boubeé et al., 2003). In the North Island, there is considerable potential for additional stocking of such waterways, especially the many small dams and ponds that proliferate throughout much of the farming country. For example, there are more than 28 000 lakes and ponds <0.5 ha in the North Island (Table 2), many of which do not contain eels. Industry sees seeding many of these lakes with juvenile eels as a means of maintaining high productivity to offset possible reductions in harvest of riverine stocks of eels.

Smaller scale transplants have also been trialled as a means of enhancing both shortfin and longfin customary eel fisheries in both islands. Transplants have generally proved successful, although the use of small eels captured in areas of high density has probably resulted in a disproportionate ratio of males in receiving waters, with subsequent emigration of these at maturity (Beentjes and Jellyman, 2003). A recent review of factors associated with the onset of sexual differentiation confirmed the significance of density as a major factor (Davey and Jellyman, 2005).

Present government management strategy emphasizes elver transfers as an effective means of stock enhancement. Additional emphasis has been placed on establishing the extent and adequacy of silver eel escapement, the reduction in catch of longfin eels, and setting aside of additional reserves for the species. There has also been increased recognition of customary Maori fisheries through assessing the wellbeing of eel stocks and opportunities for enhancement.

It is recognized that maintaining and preferably enhancing adult escapement is arguably the most effective measure for maintaining the sustainability of stocks. Fortunately, the importance of maintaining eel passage both up- and downstream is now widely recognized and required by Regional Councils, the statutory authorities that manage fresh-water resources. Habitat management and control of exotic invasive plants and animals is critical to maintaining aquatic biodiversity; longfin eels are New Zealand’s largest native fresh-water fish, and historically eels dominated the biomass of all waterways, often constituting >90% of total biomass (Hicks et al., 2004). With the loss of significant numbers of large longfins, there is now concern about the ecological impacts of this on lower trophic levels (Jellyman et al., 2000; Chisnall et al., 2003).

Concerns

Fishery management

In response to concern about the wellbeing of longfin eel stocks, fishery managers are taking active steps to reduce exploitation, including setting the TACC for North Island longfins at a level below recent catches, and the setting aside of three significant rivers as free from commercial fishing. However, it is debatable whether such measures are extensive enough to forestall the predicted major reduction in recruitment of the species (Jellyman et al., 2000; Jellyman, in press). Although the QMS provides upper harvest limits, these have been mainly set from catch histories, because the biological data are inadequate. Results from economic modelling (Doole, 2005) suggest that this management strategy will not permit stock recovery and may indeed lead to stock collapse. There are further concerns that the system does not provide enough fine-scale management (at a catchment level), that quotas have not been adjusted since their inception, and that little recognition has been paid to enhancement of stocks by elver transplants.

In response to such issues, fishery managers are investigating finer scale management units. Many Maori are still basically opposed to the commercial exploitation of eels, believing they should be utilized for customary and recreational purposes only. Apart from a general concern about lack of availability of larger eels, Maori have also expressed concern about the need for protection of additional areas of high customary importance. Given that shortfins are an Australasian species, there needs to be more recognition of integrated management between Australia and New Zealand.

Habitat

Because they migrate extensively inland, longfin eels have also been negatively impacted by the installation of weirs and dams. Historically, no provision was made for upstream or downstream passage of eels, because reduced abundance or exclusion upstream was deemed to be favourable to recreational fisheries based on imported brown and rainbow trout. The resulting exclusion from upstream habitats has been extensive. For example, a series of eight hydromats on the Waikato River (the largest river in the North Island) effectively excluded eels from 30% of this catchment. Likewise, installations of major hydroschemes on large South Island rivers (Waiau, Clutha, and Waitaki) collectively impacted upstream recruitment to more than 20% of the whole of the South Island. Fortunately, facilities are now in place at most major hydromats to facilitate upstream recruitment of juvenile eels, and managers from several hydrocompanies are investigating options to assist downstream passage of silver eels.

Being principally a lowland species, shortfins have been significantly impacted by the loss of up to 90% of New Zealand’s wetlands, and the extensive channelizing and straightening of lowland rivers over the past 50+ years. Current practices of waterway management (removal of sediment and aquatic weeds to facilitate drainage, by mechanical and chemical means from 15 500 km of waterway each year; Beentjes et al., 2005) result in widespread loss of habitat and also in direct mortality of eels when they become stranded on banks. Several regional councils are taking steps to reduce such impacts, including employing people to return stranded eels to waterways. The impact of these practices on eels is unstudied, but collectively they must be substantial.

Table 2. The number of lakes of different size in North and South Islands of New Zealand.

<table>
<thead>
<tr>
<th>Lake area (ha)</th>
<th>North Island</th>
<th>South Island</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.5</td>
<td>28 209</td>
<td>19 405</td>
</tr>
<tr>
<td>0.5–0.9</td>
<td>1 656</td>
<td>1 636</td>
</tr>
<tr>
<td>1.0–9.9</td>
<td>1 212</td>
<td>1 898</td>
</tr>
<tr>
<td>10–99.9</td>
<td>156</td>
<td>400</td>
</tr>
<tr>
<td>100–999</td>
<td>41</td>
<td>76</td>
</tr>
<tr>
<td>1 000–9 999</td>
<td>11</td>
<td>18</td>
</tr>
<tr>
<td>&gt;10 000</td>
<td>1</td>
<td>7</td>
</tr>
</tbody>
</table>
In addition, there are extensive pumping systems in some regions, and intakes are often unscreened and result in unreported deaths of eels. Several decades ago, eels were regarded as nuisance species. Fortunately, however, their status has now changed and Regional Councils are required to protect indigenous fish species. Councils now routinely require installation of fish passage facilities at weirs and dams, fish exclusion facilities at irrigation and hydro-intakes, and often encourage minimal mechanical stream clearing.

Conservation
Previous investigations of the extent of reserve areas for eels (Jellyman, 1993) suggested that a nominal target of 20% of species habitat should be set aside, although, as emphasized by Doole (2005), there are insufficient biological data to use in optimal reserve design. A recent survey using GIS techniques to estimate total lengths of waterways and areas of lakes (Graynoth and Niven, 2004) estimated that 14% of the total biomass of eels in the West Coast and Southland regions of South Island (representing approximately one-third of the total area of South Island) were fully protected, with a further 14% largely protected (except that silver eels could theoretically be exploited when they migrate from reserve areas). However, given that there is evidence of continued growth-overfishing and decreased recruitment of longfins (Jellyman et al., 2000; Hoyle and Jellyman, 2002; Doole, 2005), escapement from present reserve areas must be considered inadequate, and reservation of additional areas is essential.

For shortfins, it is not known to what extent marine stocks provide a largely unexploited buffer for spawning escapement. Although the species is shared with southeastern Australia, management is carried out independently by both countries. Irrespective of whether A. australis is considered a single species (Jellyman, 1987; Dijkstra and Jellyman, 1999) or possibly two subspecies (Schmidt, 1928; Watanabe et al., 2005, 2006), it should be treated as a single fish stock and managed cooperatively by both countries. Research has indicated that although glass eels are genetically homogenous at recruitment (Smith et al., 2001), some selection (e.g. temperature-based) appears to take place during the fresh-water phase. An important corollary of this is that adult escapement should be maintained over a wide geographic area to maintain this genetic heterogeneity.

Conclusions
The commercial harvest of fresh-water eels in New Zealand has declined progressively over the past decade, mainly as a result of more restrictive fisheries management. The commercial fishery is a valued one, with an estimated asset value of NZ$ 23 m (Statistics New Zealand, 2005). Widespread concerns that the endemic longfin eel has been overexploited have led to a recent acknowledgement by fishery managers that current levels of exploitation are not sustainable [Ministry of Fisheries, Science Group (Comps), 2006]. Despite the additional gazettation of reserve areas, it is considered unlikely that such measures will be sufficient to arrest a predicted substantial decline in recruitment of this species. Although levels of concern for the status of shortfin eels are not similar, both customary and commercial harvests of this species are almost exclusively of females; this fact alone means that the fishery must be closely monitored and managed to ensure that there is no similar decline in stocks.

Acknowledgements
I thank my NIWA colleague, Eric Graynoth, and Peter Todd and Dave Allen of the Ministry of Fisheries for helpful comments on the manuscript. Additional comments from two referees, Brian Knights and Bruce Pease, also led to improvements in the text.

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doi:10.1093/icesjms/fs073