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The Potential for Sea Ranching of Salmonids in Tasmania

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Introduction

Sea ranching consists of raising and releasing juvenile salmonids (salmon or trout), which then migrate to the sea, where they live for up to several years. The fish are harvested on their subsequent return to the area where they were released.

Successful sea ranching thus involves the collection of energy and nutrients from a wide expanse of ocean, and its packaging, transport and concentration in a focussed nearshore area for convenient harvesting. About 99% of the food consumed by sea-ranched salmon during their lifetimes is taken in the wild. This contrasts with farmed salmonids (i.e. fish raised in cages or ponds), which are fed commercial rations throughout their lives. Ocean-ranched fish usually attract a market premium over pond- or cage-reared fish (see Field-Dodgson, 1986).

In the North Pacific, sea ranching of salmonids is carried out in Japan, the USSR, Canada and the United States. Over 30% of the salmon caught by recreational and commercial fishermen are sea-ranched. The commercial fishery is worth an estimated $US350 million annually. Although the value of the recreational fishery is more difficult to estimate, it is also believed to be worth several hundred million dollars.

Early attempts to establish sustained sea runs of salmon in Tasmania, New Zealand, the Falkland Islands and South America consistently failed. But subsequent attempts in New Zealand with chinook salmon were successful, as were renewed efforts in Chile with chinook and coho salmon.

A recent Report of the Select Committee of the House of Assembly on the Freshwater Sport Fishery (1986) has raised once again the question of establishing stocks of sea run salmon in Tasmania. Our knowledge of the biology and environmental requirements of salmonids has improved greatly since the time of Tasmania's earlier attempts. Because of this, and in view of the successes now being achieved elsewhere in the Southern Hemisphere, it is reasonable to ask whether Tasmania should try once again.

Tasmania has certain advantages over most countries where sea racnhing is being practised. Sea ranching in countries where salmon move into international or foreign waters is often faced with the problem of foreign fishermen taking significant portions of the harvest (e.g. Saunders, 1977; Fraidenburg and Lincoln, 1985; Netboy, 1985[1] : Joyner, 1986). This forces almost all salmon fishing nations to compete for the fish at sea before they move into coastal waters on their spawning migrations. This was one of the main reasons for Norway, the world's biggest salmon farming nation, opting for cage culture over sea ranching, despite the greater costs.

All salmon-ranching nations in the Northern Hemisphere face this problem. Tasmania would not (although fishermen from other Australian states could conceivably have access to a portion of the stock — this will be discussed further below).

[1] Netboy (1985, p. 43) states, for example, "Sweden now releases about 2 million salmon smolts annually or a third of the total smolt releases (for sea ranching) in the Baltic Sea. The Danes, who have exterminated their own salmon, are the major beneficiary for they take the major portion of the Balticcatches"

The commercial ocean fisheries for salmonids in the northern Pacific and Atlantic are also economically inefficient. The fuel costs, the capital investments in offshore boats and gear, and the catching of the fish before they have reached full size are all very wasteful. Larsson (1982) calculated, for example, that if fishing with drifting gears stopped and salmon were harvested during their spawning migration, the value of the catch in the Baltic Sea area would double.

Under the Tasmania Fisheries Act, harvesting of salmonids in marine waters is prohibited. In the event of sea ranching in Tasmania, this legislation could be amended to ensure that the commercial harvest occurred in coastal waters and rivers. Such a fishery would not only be more economical than sea fisheries, but it would also much more easily monitored and managed.

The legislation could also be amended to give a commercial producer exclusive rights to harvest the commercial catch. Both these legislative changes would be easier to effect, given the present legislation banning commercial salmonid fishing in marine waters, than if no such provision existed (Marc Wilson, pers. comm.)

Because of Tasmania's existing trout and salmon industry, sea ranching could also be undertaken without some of the startup and capital investment costs that would otherwise be required.

Salmonids Available in Australia

Here we examine the sea-ranching potential of the five species of salmonids present in Australia. We identify one species as superior to the rest, and single out the areas of the state in which sea-ranching trials with it appear most likely to succeed. We also point out some of the potential problems.

Australia is free from most of the serious diseases that plague many salmon hatcheries in other parts of the world. To keep it that way, Commonwealth law prohibits the importation of salmonids or their ova. Thus Australia is limited to sea-ranching trials with species already present in the country. These species are:

Atlantic Salmon	*Salmo salar*
Brown trout	*Salmo trutta*
Rainbow trout	*Salmo gairdneri*
Brook trout	*Selvelinus ontinalis*
Chinook salmon	*Oncorhynchus shawytscha*
(also called Quinnat, King or Spring Salmon)	

We will omit one of these species from further consideration at the outset. The brook trout, *Salvelinus fontinalis,* has never done well in Tasmania. Brook trout were imported twice. The first shipment, in 1883, did not result in self-supporting populations. Portions of a second shipment from Canada in 1962 were released into eight lakes. Only one self-supporting population still exists — in Clarence Lagoon. Brook trout appear unable to compete with either brown or rainbow trout in Tasmanian waters or in New Zealand. In the absence of interspecific competition (i.e. in hatcheries), young brook trout grow well, but their rate of survival if they were released in Tasmanian waters could well be low. Moreover, to our knowledge, there are no sea-run populations of this species to compare in size with those of some of the other species listed above, and no commercial sea ranching operations that we know of.

3 General Background on Species under Consideration

Atlantic Salmon

Atlantic salmon, *Salmo salar,* are native to the coastal drainage systems of eastern Canada and the northeastern United States, Greenland, Iceland and Europe. Many stocks of this fish have been depleted through overfishing and environmental degradation of their freshwater habitats. Wild stocks have been eliminated in such countries as Denmark, Portugal, Holland and the nited States. Enhancement of depleted stocks has been undertaken throughout the region, with varied results.

Adult Atlantic salmon do not feed in freshwater during their spawning run (Jones, 1959). They do, nevertheless, respond to anglers' lures. They are famous for the outstanding recreational fly-fishing they support on their return to their spawning streams. Unlike a number of other sea-running salmonids, including brown trout and chinook salmon, they do not, however, support a marine or estuarine recreational fishery.

Atlantic salmon support important marine commercial fisheries in the north Atlantic. They also support a large and rapidly expanding sea-farming industry in a growing number of countries in the temperate zone, including Tasmania. Atlantic salmon fetch premium prices on the commercial market. There is growing concern that the market appears to be nearing saturation, however, because of rapid increases in world sea-farming production of the species (e.g. Anonymous, 1986a; 1987a).

Brown Trout

The original distribution of brown trout, *Salmo trutta,* includes the rivers and lakes of all of Europe, of north Africa and of western Asia as far east and south as Afghanistan and Pakistan. Many populations are landlocked. Brown trout that run to sea are less widely distributed, being found in Iceland and Scandinavia and rivers flowing into the White Sea and Cheshkaya Gulf, the Baltic and North Seas, Western Britain, Ireland and the Bay of Biscay in the Atlantic. Introductions have been made world-wide, many resulting in self-sustaining populations, as in Tasmania.

It was once thought that nonmigratory and sea-run trout were distinct species[1]. All forms are now recognised as *Salmo trutta.* Both resident freshwater and migratory sub-populations spawn in the same habitat (Jonsson, 1985). Jonsson considers that resident and migrant brown trout are parts of the same 'demes' (local populations) and that both genetics and environment influence whether these fish become resident or migrant.

In most Australian waters, including those in Tasmania, brown trout attain much higher densities than rainbows in most of the waters where both have been introduced.

Sea-run brown trout are well favoured by sports fisherman in Tasmania. They are caught by baitfishing, spinning and fly fishing

[1] In Europe, sea-run brown trout are often referred to as "sea trout". This is a confusing term, since several other species of trout also run to sea. In western Canada, for example, at least four species of trout migrate to saltwater, where they are all referred to as seatrout. We will not therefore use the term "seatrout" in this report.

when they move into the rivers to feed or prior to spawning. (They are also caught illegally by gillnetting.) But, as elsewhere, they do not occur in sufficient numbers to support a recreational fishery of the size of the chinook salmon, steelhead or Atlantic salmon fisheries in the northern hemisphere, nor of chinook salmon in New Zealand.

Sea-run brown trout are caught commercially as a sideline to Atlantic salmon in some areas of the north Atlantic, but nowhere do they support a major commercial fishery. In Scotland, for example, commercial catches of sea-run brown trout between 1954 and 1968 averaged about 230 tonnes (Mills, 1971).

It is against the law to sell brown trout in Tasmania. If this law were ever changed, which seems unlikely because of the resistance of recreational fishermen[2], then brown trout would probably, like rainbow trout (see below), command much lower prices than either Atlantic or chinook salmon.

Rainbow Trout

Rainbow trout, *Salmo gairdneri*, are native to coastal drainage systems from north-west Mexico to western Alaska. As with brown trout, many rainbows living in rivers with access to the sea nevertheless remain throughout their lives in freshwater. Those that do run to sea are referred to as 'steelhead'. These fish usually migrate to sea after spending two years in freshwater.

Steelhead are probably the most highly prized sports fish among the Pacific salmonids (Solomon, 1984). The recreational fishery is limited largely to freshwater. Steelhead stocks are often smaller than those of Pacific salmon in the same waters.

Rainbow trout raised in sea cages command much lower prices than salmon. We suspect wild-caught steelhead would fetch prices higher than pen-raised rainbows but lower than wild-caught Atlantic salmon.

Chinook Salmon

The young and spawning adults of chinook salmon, *Oncorhynchus tschawytscha*, are native to most rivers along the west coast of North America from southern California to northern Alaska, and in north- east Asia from the Anadyr River in Siberia to northern Hokkaido. Stewart (1980, p. 438) points out that, "The distribution of this species suggests that it is adaptable and can tolerate marked changes in its habitat". Young chinook salmon typically spend less time in rivers before migrating downstream than do the other species considered here.

Chinook salmon are the largest of all salmonids, with an average weight of about 12 kg (Netboy, 1974). Because of their large size (up to 40 kg), chinook produce more eggs per female than other salmonids; commonly more than 5,000 according to Campbell (1980).

Chinook salmon rank very high with sports fishermen. In North America, recreational fishing is carried out mainly from boats in sheltered nearshore marine and estuarine waters and involves trolling with plugs, spoons or flies, bait casting and spinning. Although adult

[2] Regulation of the sale of brown trout would almost certainly encourage poaching of wild stocks.

fish do not feed once they enter fresh water, they nevertheless take plugs, spoons and occasionally flies. About 20,000 fish — a small percentage of the recreational catch of chinook salmon in Washington State — are taken in fresh water (Haw, 1985). In New Zealand,there are no estuaries or sheltered marine waters of any size in which to troll for these fish; most are caught by casting weighted metal lures from shore near river mouths. In at least one New Zealand river, half the catch is made after the fish have moved upstream beyond the river mouth (Graynoth, 1972, cited in Stewart, 1980).

Chinook have always made up a minor portion of Pacific salmon production; only 10% of the United States commercial catch is of this species (Galat, 1981). Because of this, and its high quality as a fresh or smoked product (see below), it ranks with Atlantic salmon as the highest-priced of all salmon.

History of the Introduction of Salmonids to the Southern Hemisphere

Examining the history of introductions of salmonids in the Southern Hemisphere provides essential information for determining the relative suitability of the four species under discussion for sea ranching in Tasmania.

New Zealand

Seven salmonid species have been established as wild populations in New Zealand, including all four species discussed here.

Atlantic salmon

Between 1868 and 1907, twenty-three different importations (nearly 3 million Atlantic salmon ova in all) were made. The resulting fry were released throughout the country, albeit mainly in Southland and Otago (provinces of the South Island). All releases were unsuccessful; fish migrated to sea but never returned.

From 1908 to 1911, three importations from Canada, Germany and Britain resulted in the release of approximately 1,872,000 fry into the Upukerora River and Lake Te Anau. Progeny of these fish — and possibly a few from one importation of sebago salmon (land-locked sub-populations of Atlantic salmon) in 1905 — make up a small population of Atlantic salmon that do not run to sea, but spend their entire lives in the lake and its headwaters today (Gibbs, 1981; Flain, 1981).

In a further attempt to establish sea runs of Atlantic salmon, a few ova originating from strains of fish thought to migrate relatively short distances from the coast were imported from Scotland (1960), Sweden (1961) and Poland (1965) and released into the Waiau and Upper Oreti catchments. These introductions failed (Gibbs, 1981).

Brown and rainbow trout

Brown and rainbow trout were first imported to New Zealand in 1867 from Britain and in 1878 from America. Both species established self-supporting populations. Although migratory and nonmigratory forms of both species were stocked, only brown trout established modest sea-run populations. In the mid-1970s, renewed attempts to establish sea-run rainbow trout stocks were undertaken, supported by much improved knowledge of appropriate methods. These efforts failed (McDowall, 1984).

Chinook salmon

Chinook salmon were first stocked between 1875 and 1878, with the intent of establishing recreational fisheries. These efforts did not produce a self-maintaining stock. However, in the early years of this century, the New Zealand Government became interested in establishing commercial salmon fisheries comparable to those on the west coast of the United States and Canada, and made more ambitious efforts to establish chinooks (McDowall, 1984). Five importations between 1901 and 1907 led to the release of nearly 500,000 fry and fish one year old and over. This time they were successful.

Chinooks established self-supporting sea runs in rivers on the east coast of the South Island, from the Waiau River south to the Clutha River. They are also found in some west coast rivers in small numbers. McDowall (1984) suggests that the present distribution of chinook in New Zealand reflects the habitat tolerances of these fish rather than the efforts of acclimatisation societies which pursued a policy of 'widespread and massive releases'.

Some plantings produced self-propagating freshwater populations, a most uncommon feature within this species' native range (Flain, 1981a).

From 1907 onward, eggs for propagation could be collected from fish returning from the sea to spawn. But catches declined over the years because water-catchment areas were modified for hydro-electric projects and water extracted for irrigation projects. In 1960, as a result, all commercial licences were revoked to preserve the remaining stocks for recreational fishing (Kennedy, 1987). Nevertheless, stocks continued to decline.

In the 1970s, New Zealand's strong recreational fishing lobby decided that salmon runs must be augmented. The lobby argued that this could best be done by lending political support to commercial sea ranching; with appropriate safeguards in the commercial permits, the fish available to anglers would increase, while the commercial salmon industry would provide additional justification for protecting remaining salmon rivers against modification for hydro-electric or irrigation purposes. Initially commercial projects were restricted to those aimed principally at sea ranching (Waugh, 1980; Kennedy, 1987). By 1986 there were 10 sea-ranching, 14 pond-rearing, and 10 sea-cage farms in New Zealand, and 5 more sea-ranching facilities were in various stages of planning and development (Weeber, 1987).

A return rate of about 1.5% high-grade fish is often taken as the figure at which salmon ranching becomes profitable[1]. Within four years of beginning experimental sea ranching, such return rates have been attained in New Zealand (Gillard, 1985). In 1986 one firm recorded a return of 10,000 salmon to a new coastal site (C. L. Hopkins, pers. comm.).

By 1985 New Zealand was producing more chinook eggs than it could use (Waugh, 1985). According to Kennedy (1987), "Cage farms have the advantage of producing fish all year round and most ocean ranchers in New Zealand, realising this, run cage operations as well. However it is probably fair to say that it is ocean ranching that has most caught the imagination of salmon farmers and the New Zealand public, and that it is ocean ranching that provides the quality of product for New Zealand farmers to compete successfully on the world market."

In New Zealand the average weight of chinook salmon is only about 4.5 kg because, although the fish grow as fast as, or faster, than they do in the Northern Hemisphere, they return to their parent streams on the average of about one year earlier (Waugh, 1980).

[1] Hardy (1980) points out, however, that because of chinook salmon's large size and high market value a figure of 1% may be more appropriate for this species.

Chile

Early in this century many plantings were made in Chile of brown, brook and rainbow trout and Atlantic, coho and chinook salmon. Only brown and rainbow trout became established. Records show what appears to be continuous hatchery production of Atlantic salmon from 1916 to 1938, and more than a million salmon were released between 1928 and 1932 (Mendez, 1982), but without success. Catches and sightings of "salmon" in earlier days usually turned out to be sea-run trout (Joyner, 1980).

During the 1920s and 1930s, large quantities of sockeye, coho and char (over 100,000 of each) were imported and released, also without success (Mendez, 1982). Renewed interest in the late 1960s saw the release of coho salmon smolts and in the 1970s, of cherry salmon and over 8 million chum salmon fry from Japan. None of these introductions resulted in self-supporting populations (Nagasawa, 1981; Mendez, 1982).

In 1985 a Chilean company was releasing chinook and coho salmon at the rate of 1.0 – 1.5 million smolts per year and achieving returns of about 1% (Brown, 1985; cited in New, 1987). Success was attributed in part to releasing the fish in rivers in the southern part of the country, where ocean temperatures and prevailing currents are likely to be more suitable than in areas to the north where fish had previously been released

Argentina

Argentina's attempts to acclimatise salmonids began in 1905 with introductions of chinook, coho, sockeye and Atlantic salmon, but were unsuccessful. Several species of trout and sebago salmon (freshwater resident Atlantic salmon) were also introduced. By the 1930s, permanent stocks of brown, rainbow and brook trout and sebago were established (Stewart, 1980). Recently, 40,000 Atlantic salmon fingerlings were planted in a number of rivers (Joyner, 1980). We have not located any reports suggesting that sea-run populations of any salmon have become established.

Falkland Islands

Brown trout were stocked in the Falkland Islands in the late 1940s. They became well established within a few years and a sea-run habit developed. As elsewhere in the Southern Hemisphere, efforts to establish sea-run Atlantic salmon failed (Stewart, 1980).

Tasmania

Australia was the first country in the Southern Hemisphere to receive viable shipments of salmonid ova, and Tasmania was the first place to which they were introduced (Nicols, 1882, cited in Scott, 1985). The history of these importations for the one hundred years prior to the ban on live fish imports can be found in the Annual Reports of Fisheries Commissioners in Tasmanian Parliamentary papers. Short gaps exist in the records from 1893–1908, 1929–1933 and during World War 1. A detailed account of these introductions is given by Alexander (1987). The table below summarises the introductions and present distribution and status of the salmonids considered in this report.

Species	First introduced	Present distribution
Atlantic Salmon	1864	Stocked in lakes – NSW Raised in sea cages – Tas.
Brown trout	1864	Widespread in Tasmania and southern mainland
Rainbow trout	1894	Widespread in Tasmania and southern mainland
Chinook salmon	1910	Stocked in two lakes – Vic.

Atlantic salmon

After several shipments of ova died during transport, a number of Atlantic salmon and brown trout ova survived the journey from Britain in 1864. A small percentage of these hatched at the newly built Salmon Ponds hatchery, and about 4500 Atlantic salmon fry and 38 brown trout fry were subsequently released into the Derwent River system. Four importations of Atlantic salmon were made between 1864 and1885, originating from various rivers in Britain. These resulted in the release of 35,000 fry and smolt into the Derwent River system and other Tasmanian rivers.

Several accounts of returning Atlantic salmon in the Derwent were recorded. Identification of these fish was controversial, however. Three specimens were sent to the British Museum: one was pronounced to be a young salmon and the others, brown trout (Nicholls, 1961). Subsequent importations of *S. salar* involved "sebago", a land-locked variety, which failed to become established. There is doubt that a substantial sea-going run of Atlantic salmon was ever established in Tasmania even for a short period of time (Stewart, 1980) .

Between 1963 and 1965 migratory "fall-run" Atlantic salmon from the Copequid Fish Culture Station, Philip River, Nova Scotia, Canada were imported to New South Wales (Francois, 1963; MacCrimmon and Gots,1979). These fish have been propagated at the Gaden hatchery, New South Wales, in a freshwater environment for over 20 years. In the past 3 years progeny from this stock have been used to establish sea-cage farming in Tasmania. The fish are spawned and raised to smolt stage in a hatchery, then transferred to cages in estuaries in the southeastern part of the state, where they are grown to market size (Hortle, 1986).

Brown trout

Comparatively few brown trout were originally imported to Tasmania; early efforts focussed mainly on Atlantic salmon. In the early days, sea-run brown trout were mistakenly considered a separate species. The first importations of sea-run browns (Tweed River, Scotland, 1866) were released into many Tasmanian rivers in small numbers. Between 1926 and 1928 three more shipments of ova were received from 'Solway Fisheries' in Scotland (Nicholls, 1961). Many of these, and subsequent generations, were released into the River Derwent.

It is difficult to estimate the number of brown trout released around the state. Over the period, 1869–1872, approximately 2800 sea-run ova and fry and 30,000 resident brown trout were distributed. Releases during

1926–1937 totalled over 50,000 fry, yearling and two-year-old fish, which went mainly into the River Derwent.

Brown trout are by far the most 'successful' salmonid in Tasmania today. Self-supporting freshwater populations now occupy most lakes and streams, and sea runners are now found in many estuarine and coastal waters. Brown trout were also successfully introduced into in southeastern Australia and the southwest corner of Western Australia.

Rainbow trout

Rainbow trout were first introduced into New South Wales from New Zealand in 1894 (MacCrimmon, 1971). The origins of New Zealand stocks have been established only recently. Both sea-running stocks (referred to as 'steelhead') and non-migratory stocks were involved, but it seems that a major influence on New Zealand stocks was an importation from Sonoma Creek, California, which most likely consisted of steelhead (Scott, 1985).

Ova were distributed from New South Wales hatcheries to Tasmania and other Australian states (Weatherly and Lake, 1967). From 1919 to 1936, ova were imported directly to Tasmania from New Zealand and released mainly into Lake Leake and Great Lake. Over 1948-1951, 22000, 6650, 5400 and 9500 yearling *Salmo gairdneri* were released into the Forth River. Sea-run stocks failed to become established.

Today, self-supporting populations of rainbow trout are found in many freshwater lakes and streams in Tasmania. Individuals are occasionally caught in estuaries. Brown trout tend to dominate in most waters containing both species. The Inland Fisheries Commission enhances rainbow trout populations by providing artificial spawning beds such as those at Zig-Zag Canal at Liawenee, Great Lake, using the progeny for restocking. Rainbow trout are also found in southeastern Australia and the southwest corner of Western Australia.

Trout farms in Tasmania stock rainbow trout for production of flesh as well as ova for export. Sea-cage farming of this species has recently proven successful.

Chinook salmon

Early chinook introductions into Tasmania spanned the years from 1910 to1923, with a short interlude during 1918–1921 when New Zealand was unable to supply ova. Over 240,000 fry were liberated, mainly into the River Derwent. These averaged about 15,000 annually, although about 45,000 fry were released in both 1922 and 1923. Batches of fewer than 2,000 yearlings were also released into the River Derwent from 1913 to 1928.

Self-supporting stocks of chinook did not become established in any Tasmanian rivers. (There are rumours that a limited run exists in the Henty River on the west coast, but the last authenticated sighting was in 1946 [P. Davies, pers. comm.]. Large sea-run brown trout are caught in this river, and it would be easy for a fisherman to mistake one of these for a chinook.)

In 1967 chinook salmon were planted in Great Lake. The fish grew well and provided a good fishery for a few years, but failed to spawn. At the Snobs Creek hatchery in Victoria 'fall-run' stocks were imported in 1966 from the Columbia River in Oregon (Rogan, 1981). These are bred artificially at the hatchery and used to stock Lakes Purrumbete and

Bullen Merri with 20,000 fish each (Rogan, 1981; Hames, pers. comm.). No natural spawning occurs, probably because of excessively high water temperatures, which can exceed 20°C in summer (Hames, pers. comm.). There is now a guaranteed production of several hundred thousand chinook salmon eggs per year at the hatchery.

Status of Introductions: Species Summary

Atlantic salmon

Introducing the Atlantic salmon to waters within its natural geographic range, but in which it does not naturally occur (i.e. in the Faroe Islands and in certain rivers in eastern Canada) has met with some success (R. Saunders, pers. comm.). Land-locked populations have also been established in New Zealand (Gibbs, 1981) and Argentina (Joyner, 1980). *Many and widespread efforts to establish significant populations of sea-run Atlantic salmon in waters outside the north Atlantic region, including those of Tasmania, have, however, met with consistent failure.* In New Zealand, as noted above, over five million ova were imported, yet, "there was no compelling evidence that a single sea-run (Atlantic) salmon has ever returned to New Zealand's rivers" (McDowall, 1984, p. 202).

Although little or no commercial production of Atlantic salmon occurs in New South Wales, fish derived from this stock are used in Tasmania's new sea-farming industry.

Brown trout

Freshwater resident populations of brown trout have been successfully introduced throughout the world. These fish often developed sea run stocks where they were introduced into waters connected with the sea. At present, sea-run brown trout support a minor recreational fishery in Tasmanian estuaries[2].

Rainbow trout

Freshwater resident populations of rainbow trout have been successfully introduced throughout the world (MacCrimmon, 1971). Many of these have become self-supporting. But as with Atlantic salmon, sea-running stocks have been established only in areas within the normal geographic range of the species, as in Oregon (Lannan, 1980). When steelhead are introduced outside their normal geographic range, their populations, if they survive, invariably revert to an entirely freshwater existence[3].

Chinook salmon

Early introductions of chinook salmon included widespread releases in the United States and Europe (Davidson and Hutchinson, 1938, cited in Solomon,1980). All failed to establish sea-runs, although fresh-water populations now exist in the North American Great Lakes (Withler, 1982).

As discussed above, early attempts to introduce chinook salmon to the Southern Hemisphere, including Tasmania, failed. But New Zealand subsequently succeeded in establishing self-supporting runs, and recent efforts in Chile have produced self-sustaining sea runs (H. F. McDonald, pers. comm.).

In Australia, chinook salmon are maintained at the Snobs Creek hatchery in Victoria, where hatchery-raised fry are used to stock two lakes and research is carried out on sea farming.

[2] Currently an estimated 7,000 sea-run brown trout are caught around the mouth of the River Derwent, the state's largest estuary, whereas some moderate-sized lakes yield over 100,000 fish to anglers each year (Inland Fisheries Commission unpublished data).

[3] In the 1930s, steelhead introduced in Chile returned from the ocean to their natal rivers for several years before the stock all but disappeared. Steelhead are still occasionally taken, however (H. F. Mc Donald, pers. comm.).

Explanations for Past Successes and Failures

It is likely that more research has been done on migratory salmonids than on any other small group of marine fishes (Miller and Brannon, 1981). Considerable effort has been made, especially in the 1980s[1], to: (1) define hatchery requirements for fast growth, low disease incidence, and high return rates, (2) discover the freshwater, estuarine and marine conditions required for the high survival and rapid growthof released salmonids, and (3) determine what makes some introduced salmonid species more likely than others to return from the ocean to their natal streams and what oceanic conditions favour this return.

Such knowledge has enabled researchers to improve returns and increase the stability of captures between years in existing hatchery-supported salmonid fisheries. It has also yielded a better understanding of why so many previous salmonid introductions failed, as well as a much sounder basis for selecting species for future introductions and designing protocols for rearing and release.

Shipping and Hatchery Mortality

Very early records of salmonid importations to Tasmania (for summary, see Alexander, 1987) show that the number of ova imported greatly exceeded the number of fry actually released. This implies that there was considerable mortality among ova and/or fry. Early conditions at the Plenty hatchery were probably less than ideal for hatching and rearing. In 1884, for example, there were high mortalities of brown trout broodstock.

Nicholls (1961) attributed the failure to establish Atlantic salmon in Tasmania to the relatively low survival of ova to fry stage. Joyner (1980) also mentions this in explaining the lack of success with this species in South America. Factors likely to contribute to this include: heavy mortality during transportation of original imports (which came by sea packed in moss on ice — a journey of many weeks [Seager, 1899]); poor hatching success; inappropriate handling prior to release; and disease. In one year, half of the 30 Atlantic salmon broodstock at the Plenty hatchery in Tasmania were effectively culled, according to Saville-Kent (1885), who identified the cause as the fungus, *Saprolegnia ferax.*

Numbers Planted

Early attempts to establish sea-run salmonids typically involved dividing the limited available stock into relatively small portions, which were released in several or many different rivers. Joyner (1980, p. 272) points out the shortcoming of such a strategy: "the number initially needed to produce a breeding population must be far greater for sea-going salmon than for freshwater trout. Compared to the relatively limited space of lakes and rivers inhabited by trout, the vast spaces of the open ocean into which salmon venture can easily swallow up the small populations produced by limited plantings."

In addition, alevins (hatchling salmonids emerging from the gravel of the spawning beds) are subject to predation by prey whose year-round residence in the area indicates that they are not likely to be limited by

[1] Three-quarters of the references in this report, for example, are to publications dated 1980 or later.

the alevin abundance. Consequently, these predators are liable to consume a relatively constant number of alevins, irrespective of the number present. This "depensatory mortality" (Neave, 1953) implies that the smaller the hatch, the greater the proportion that will be consumed.

The many failed early attempts to establish sea-run chinook populations in New Zealand, as elsewhere, involved dividing the eggs and young into small consignments and planting them in many rivers. It was only (and immediately) after the decision was implemented to plant all available stock in one river for a number of successive years that success was achieved (e.g., McDowall, 1984).

McDowall (1984) considers that later efforts to introduce chinook into New Zealand succeeded largely because of the 'intensive' effort expended by the New Zealand Government. Crowe (1985) suggested that 500,000 eggs would be needed annually over 3 to 5 years to ensure the success of a sea-ranching operation of chinook in New Zealand. The recommended target for each planting of this species in Chile is between 100,000 and 200,00 smolts (Hatfield International S.A., 1986).

Size of Fish at Release and Time of Release

Recent research in the United States, Canada and New Zealand on a number of species of anadromous salmonids confirms that the practice of planting larger fish increases survival chances significantly (e.g., Burrows, 1981; Crowe, 1985; Bilton, 1984). In Tasmania most salmonids were released into streams as fry, rarely as yearlings. In contrast, New Zealand's successful plantings of chinook involved releasing fish as fry, yearling, two-, three-, and even four-year-olds. (In a few instances older chinook were released in Tasmania, but in very small numbers — 3,000 yearlings in King River, 5,000 yearlings in the Franklin River and 50 fish over two years old in the Plenty River (Tasmanian Yearbook, 1970).

It has also been observed that the smolts of some anadromous salmonids released into rivers later than the time at which wild smolts normally move downstream produce improved returns (Novotny, 1980; Unwin, 1985; Hardy, 1980). Late-release fish are also usually larger fish, but early research did not provide a means of distinguishing between the effects of these two factors. More recent work indicates, however, that later release date and larger size, individually as well as in combination, produce higher returns of sea-ranched chinook salmon (Unwin, 1985).

In addition, Fieldler, Smith and Laurs (1984, p. 6) have suggested that: "It might be possible to improve the growth and survival of hatchery-reared salmon by scheduling releases during periods of most favourable ocean conditions. [Satellite] imagery could be used as source of information on sea surface temperature, river plume trajectory, upwelling intensity, primary production, and the ocean front areas associated with each of these factors. Small improvements [thus achieved] in the survival of juveniles released from hatcheries could result in substantial increases in the numbers of returning adults." The CSIRO Marine Laboratories in Hobart has access to such satellite data on a daily basis.

Condition of Fish at Release

Fish being raised for release must be in excellent condition in order to compete successfully in nature. The importance of this was not fully appreciated in the early days of salmonid introductions: diets were suboptimal, overcrowding was common and disease prevention procedures were primitive.

Competition and Predation

All salmonids considered here, with the exception of the majority of chinook salmon, spend at least one year in streams before migrating to sea. If densities of competitors and or predators are high in freshwater, then high losses may result. Territorial behaviour results in the displacement of smaller salmonids to less suitable habitats (e.g., Allen, 1969; Unwin, 1986).

Survival and growth of Atlantic salmon fry improved when brown trout were removed from a northern Irish stream containing adults of both species (Kennedy and Strange, 1986). Kennedy and Strange (1980) also reported that the presence of salmon parr could adversly affect the survival of both Atlantic salmon and brown trout at fry stage. In the Falkland Islands, Stewart (1980) suggests brown trout may have preyed on planted young Atlantic salmon.

Legault and Lalancette (1987) found that predation by brook trout on Atlantic salmon fry could be prevented by allowing the fry a recuperation period after transport from hatchery to planting site and scattering them in appropriate habitats rather than releasing them *en masse*.

Temperature Limits

Preferred temperatures in freshwater for some salmonids are reviewed by Bovee (1978), and indicate that spawning fish have the most limited temperature range. In both marine and freshwater environments it is clear that the low temperatures around Tasmania do not approach unsuitable levels for salmonids, except at high altitudes. But the question of high summer temperatures in marine waters requires some discussion; this is deferred to a later section of this report.

Pheromones

There is some evidence that pheromones (substances released by organisms that influence the behaviour of other members of the same species) released by juvenile salmonids in rivers may be important in guiding adult fish back to the home stream (e.g. Northcote, 1984; Foster, 1985). This may have been involved in the successful establishment of chinook salmon in New Zealand, according to Flain (198la); uncertainty of ova supplies earlier this century, resulted in the practice in New Zealand of retaining some fish for several years as broodstock in the river of liberation.

Migration Pattern

Even in the absence of the problems discussed above, however, it is unlikely that transplantation efforts in Tasmania would have been successful for two of the four species under discussion.

A number of authors have pointed out that the stocks of the species most likely to succeed when transplanted are those that wander the least distance from their streams of origin and migrate along coastlines (e.g. Larkin, 1981; Stewart, 1982; Scott, 1985). Scott (1985), for example, concludes that the transequatorial establishment of anadromous salmonids is dependent on their ability to complete their migratory pattern, and that this probability is inversely proportional to the typical migration distance of the parent stock. He predicts the success of implanting the following species based purely on their known typical distance of migration as follows:

Species	Probability of homing
steelhead	low
Atlantic salmon	low
chinook salmon (fall)	moderate
brown trout	high

Flain (1981a) suggests that introductions of Atlantic salmon into New Zealand did not result in the establishment of sea-run stocks mainly because of the offshore migrations of this species. Atlantic salmon often travel thousands of kilometres to their oceanic feeding grounds (e.g. Went, 1973; Mills, 1971). Stewart (1980) similarly explains the failure of Atlantic salmon to acclimatise and the success of sea-run brown trout in the Falkland Islands to the migration habits of both species. Most sea-run browns usually remain in coastal waters.

He suggests that young salmon drift passively with the current for part of their life cycle. In the north Pacific and north Atlantic, there are oceanic gyres (rotating currents) with a rotational period that facilitates the return of salmon to their natal streams. But salmon traveling in the circumpolar West Wind Drift south of New Zealand, Tasmania or the Falkland Islands would take 5–6 years to make a complete circuit — a period beyond the known maximum sea life of Atlantic salmon.

Steelhead migrate directly offshore after leaving freshwater (e.g., Scott, 1985; Okazaki, 1985) and are thus presumably faced with the same difficulties in homing in foreign waters as Atlantic salmon. Chinook salmon and brown trout, on the other hand, are a "shelf-hugging" species[2] .

2 Some chinook leave coastal waters after their first year of ocean residence and move offshore considerable distances. But these offshore movements, unlike those of other salmon and of steelhead, are limited mainly to waters over the continental shelf, in this case the Bering Sea shelf (e.g., Major et al, 1978).

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Narrowing the Choice

The preceding sections provide sufficient information to enable us to eliminate two species from further consideration.

Atlantic Salmon and Rainbow Trout

As discussed above, *all attempts to establish sea-run populations of rainbow trout (steelhead) and Atlantic salmon anywhere outside their natural range have failed.* Inadequate understanding of the conditions needed for successful raising and planting of fish would appear to provide reason enough for the early failures. But more recent attempts with these two species using much improved techniques have fared no better.

There are no unusual difficulties involved in raising either species to the smolt stage. But, when steelhead or Atlantic salmon planted outside their normal geographic range leave their natal rivers for the sea, they are never seen again[1] . Thus it is in the ocean that the problem resides. And it is believed to lie in the fact that these two species typically migrate far offshore over deep oceanic waters.

Out of contact with the continental shelf, they cannot, apparently, find their way back to their places of origin unless they are located within the particular set of prevailing gyral current regimes to which they are genetically adapted — those of the North Pacific Ocean in the case of steelhead, and the North Atlantic Ocean in the case of Atlantic salmon.

At present, then, the universal failure to establish steelhead and sea-run Atlantic salmon outside their normal range, even when using much improved modern stocking procedures, does not encourage the notion that, given sufficient skill and investment, we can establish sea-running populations of either species in Tasmania.

In future this might change, perhaps as a result of selective breeding. For example, certain overseas stocks of Atlantic salmon tend to stay relatively close to their native rivers during their sea migrations and attempts are being made through cross-breeding to establish this trait in other stocks (Saunders, 1977). But results to date have not been encouraging (Saunders, pers. comm.).

The cross-breeding of steelhead and brown trout might foster an improved sea-run fishery. Brown trout and Atlantic salmon crosses might also be tried. But at present these possibilities remain untested. Hybrid fish have never, to our knowledge, been successfully used to establish sea-run stocks.

[1] Thompson (1922, cited in Stewart, 1980), provides a graphic description of the frustrations encountered in New Zealand with Atlantic salmon because of this phenomenon: "Fish have been hatched by the million, and liberated in a great number of the rivers both of the South and North Islands. Glacial streams, rivers from the great lakes, rivers from the Canterbury mountains, rapid streams, sluggish streams — all have been tried. In several cases the same river has been stocked withyoung fish for many years in succession. In many cases salmon have been reared from the egg, have been kept in confinement till they spawned, and their fry have been liberated — always in the same stream — for a succession of years, by the hundred thousand. The fish have grown well to a certain age in our waters and have then gone to sea in a normal manner, just as they do in European streams, but from that point they are lost . . . The fish has absolutely failed to establish itself." Some Atlantic salmon were even released as yearling, 2+, 3+ and even 4-year-old fish, an advanced practice almost unheard of in those times (Flain, 1981a).

Brown Trout and Chinook Salmon

The comparative ease with which sea-running brown trout populations have been established outside their normal range appears to related to their typically staying closer to "home" on their seaward migrations. Although sea-run browns have been found as far as 400 km from the mouths of their natal streams (Solomon, 1982), they are rarely found beyond the continental shelf. On their homeward journey they need only to reverse the direction in which they have been swimming and continue orienting to the shelf in order eventually to return to the vicinity of their natal river, where olfactory cues apparently guide them the rest of the way.

In addition, transplanted brown trout, unlike Atlantic or chinook salmon, readily establish self-supporting river populations. This trait probably favours the generation of sea-run stocks. Sizeable numbers of smolts are generally needed to establish viable sea-running populations of salmonids, but plantings of only small numbers have often generated self-supporting freshwater stocks. Early planting of brown trout in Tasmania involved only small numbers of fish. But the freshwater resident populations that developed from these introductions often subsequently attained considerable size. Sea-run and freshwater resident stocks of brown trout are not genetically distinct; a stock of river-resident brown trout typically includes a component that runs to sea (Jonnson, 1985). It can thus be seen that sea-running stocks need not have arisen immediately from transplantations but could have developed subsequently as sizeable freshwater stocks became established.

The failures of early attempts to establish chinook salmon appear to be related to the inadequate numbers used and the suboptimal conditions under which they were raised and released. Unlike brown trout, chinook do not establish self-replenishing river populations from which sea-running stock might be derived, thus ruling out this avenue.

We have now narrowed our search to brown trout and chinook salmon. What are their relative merits in terms of sea-ranching in Tasmania?

The strongest arguments for brown trout are: (1) as they are already in Tasmania, sea-ranching of this species would not entail quarantine; (2) as sea-run populations already exist in Tasmania, there is no uncertainty as to their ability to return from the sea to spawn; (3) their culture and biology are already the subjects of considerable study and experience in the Inland Fisheries Commission.

What, then, are their disadvantages? First, sea-ranching of brown trout would not be likely to generate a commercial fishery. It is illegal to sell brown trout in the state. If sufficient trout were generated through sea-ranching this law might, in theory, be revoked. However, the price of trout is much lower than that of salmon and the commercial incentives would be correspondingly less.

In addition, if sea-ranching of brown trout were successful it would improve the existing sports fishery, but would not, unlike successful chinook salmon sea-ranching, generate an entirely new one with the associated recreational and economic benefits (see below).

There is also the question of just how much sea ranching of brown trout would enhance existing sea runs. Brown trout spawning beds are adequate to support fully the capacities of many Tasmanian rivers for production of adult brown trout (R. Sloane, pers. comm.). To what extent are they inadequate to support maximum sea-run populations?

It is possible that sea-run brown trout would be genetically swamped by freshwater resident fish on the spawning beds, so that the ratio of sea runners to residents would be maintained at a low level. If this is the case, then the prospects for some stock enhancement by means of sea ranching would seem good.

Given the widespread existence in temperate coastal regions of sea-run brown trout populations, some of which are overfished or reduced through degradation of spawning and rearing habitats, it might be thought that attempts to enhance these populations through sea ranching would also be widespread. However, judging by the dearth of published information on the subject this does not seem to be the case.

This is probably because economic incentives to enhance sea-run brown trout stocks are relatively poor. These fish achieve greater premigratory sizes than do salmon, which necessitates a greater food input in hatcheries. They also make less weight at sea; their rearing is thus more costly (Fahy, 1893). In addition, for reasons that may have more to do with fashion than flavour, sea trout fetch considerably lower prices than salmon. Fahy (1983) concludes that the use of artifically propagated sea-run brown trout to supplement natural shortfalls is not likely to be viable.

In short, sea ranching of brown trout would require little if any expertise that cannot already be found in Tasmania, and no quarantine. But the anticipated benefits of enhanced sea-runs of this species, especially the economic benefits, do not appear to be especially attractive.

The ultimate success with chinook salmon in New Zealand and, apparently, in Chile appears to be a consequence of two things. First, the fish were raised and released in greater numbers and under more favourable conditions than was the case with early trials[2].

Second, chinook salmon generally stay on or near the continental shelf during their sea phase (a subject discussed further in the next section of this report). As with brown trout, it is this feature of their biology that appears to enable them to navigate back to their natal rivers from sea areas to which they are not native. It is noteworthy that the chinook in Victoria are derived from "fall-run" stocks, which tend to make shorter migrations than spring-run chinooks, some remaining in sheltered nearshore waters throughout their ocean lives (Hartt,1980).

Australians, being comparatively unfamiliar with salmon, tend to consider the various species as being more or less alike. But they are not, as international buyers are well aware. Chinook[3] are by far the best of Pacific salmon in terms of appearance and consumer acceptability in North America. The Japanese, who consume one-third of the world's salmon (Joyner, 1986) and import 100,000 tonnes annually (anon. 1986b) are very discriminating buyers. They prefer fat fish (Herrfuth, 1985), and chinook have the highest fat content of all Pacific salmon. This fat is more stable than that of the other species, so that mild-cured (salted) chinook can be held successfully at above freezing temperatures for many months without objectionable rancidity (Stansby, 1972). Chinook salmon share with Atlantic salmon the highest prices of all salmonids in the world's two largest salmonid markets, Japan and North America. Of the two species, chinook seems to hold the edge in terms of consumer acceptance. In the United Kingdom in 1985 frozen chinook salmon was reported to be more expensive than locally farmed Atlantic

[2] That later plantings were made further south in Chile, where more favourable oceanic temperatures and currents may also have been a factor (Mendez, 1982).

[3] A well-known John West television commercial has made the term 'chinook' suspect in Australia. Of the three other names commonly applied to this species, two are similarly unsuitable in Australia. The term 'king salmon' is often applied in Australia to the threadfin, *Polydactylus sheridani*. 'Quinnat' is an old California name no longer used there and little recognised outside New Zealand. The name of choice would thus appear to be 'spring salmon'.

salmon (Anon., 1985). In 1986 sea-ranched chinook from New Zealand fetched prices 15% higher than Norwegian Atlantic salmon in the United States (Anon., 1986c). In California in 1987 a blind-tasting evaluation of various salmon from Norway, Chile, New Zealand and the United States, chinook salmon from New Zealand were judged best (Anon., 1987b). In the New England salmon market in the eastern U.S. "the most preferred product for the expensive seafood restaurant market appears to be a fresh, troll-caught whole chinook salmon from the western United States," (Anderson, 1988, p. 12.)

Successful sea ranching of chinook salmon could generate an entirely new kind of sports fishery in Tasmanian estuarine and coastal waters. The lure of catching chinook in western North America and New Zealand is a major tourist attraction and an important source of revenue.

Drawbacks to the sea ranching of chinook salmon include the following: (1) although the biggest hatchery successes in the North Pacific have been with chinook and coho salmon (Larkin, 1977), chinook are less tolerant of rough handling than some other salmonids, such as rainbow trout (F. Hames, pers. comm.); (2) assuming rumours of a small run of chinook salmon in the Henty river are false[4], sea ranching would entail the introduction of a new species to Tasmania. The ecological implications of introducing chinook are discussed in more detail in a later section of this report.; (3) imported chinook salmon would have to undergo rigorous quarantine procedures. This subject is also discussed in more detail below.

These problems notwithstanding, it seems clear that the chinook salmon is the most attractive candidate of the five salmonid species available for sea-ranching trials in Tasmania. The other four species either offer very little hope of success, based on past experience in Tasmania and elsewhere (Atlantic salmon, steelhead, brook trout), or do not offer comparable economic or recreational advantages (brown trout).

[4] In the unlikely event that the rumoured existence of chinooks in the Henty River is true, however, this could simplify enormously the task of establishing larger and more widespread runs of this species in Tamnaia. Consequently, concerted efforts should be made to verify the rumour.

Sea Ranching Chinook Salmon

Environmental Requirements

Here we examine the environmental requirements of chinook salmon in order to determine where, in Tasmania, introductions might be expected to produce the best results.

Oceanic conditions

Significant chinook runs were established in New Zealand only in rivers that discharge along the east coast of the South Island, probably because ocean water temperatures are too high off other New Zealand coasts. All substantiated sightings of chinook salmon at sea off New Zealand have been in waters of 15°C or less[1,2], and it is only off the south and west coast of the South Island that such temperatures are found (Flain, 1981b).

Similarly, sea-surface temperatures that do not exceed 15°C are found only along the south and southwestern coasts of Tasmania (Newell, 1961).

Estuarine and sheltered marine conditions

Within their natural range, chinook have the greatest dependence on estuaries of any salmon. On their seaward migrations the fish often spend several months feeding and growing in estuaries before moving further seaward (e.g. Healey, 1982). Some chinook populations spend most or all of their subsequent sea lives in sheltered marine waters near the coast, as in Puget Sound in Washington (Healey, 1982) and Georgia Strait in British Columbia (Fraidenburg and Lincoln, 1985).

In New Zealand, chinook have proven adaptable to conditions where estuaries and sheltered marine waters are extremely limited. But many fry are washed out of suitable rearing waters and into the sea prematurely and are apparently lost (Flain, 1982). The existence of sizeable estuaries in Tasmania would thus appear to enhance chances for the successful sea ranching of chinook. In addition, as noted earlier, where extensive sheltered marine areas exist, chinook often spend all or most of their sea life there, reducing the likelihood of straying offshore. Second, such waters are generally more biologically productive than offshore waters and probably produce more food for chinook per unit area than do oceanic waters.

In the coastal waters of southeast Tasmania, dense swarms of the euphausid or krill, *Nyctiphanes australis,* (e.g. Ritz and Hosie, 1982) would appear to provide especially rich food for young chinook[3].

Finally, recreational fisheries for this species tend to be concentrated in sheltered marine and estuarine areas, in part because of the of these fish are found in high densities in such waters at certain times of the year, and in part because such waters provide sheltered conditions for small boats. We will discuss the recreational fisheries in more detail below.

By far the largest area of estuaries and sheltered marine waters in Tasmania is in the southeast in the D'Entrecasteaux Channel– Storm Bay–Derwent Estuary–Frederick Henry Bay–Norfolk Bay complex where the Huon and Derwent Rivers and other smaller watercourses discharge. Other sizeable sheltered marine and estuarine areas along the west and south coasts are Macquarie Harbour and the Port Davey–Bathurst Harbour area.

[1] Similarly, in the north Pacific Ocean, chinook are not caught in waters with surface temperatures exceeding 15°C (Major et al., 1987).

[2] Chinook salmon can tolerate water much warmer than this, and are often found at such temperatures in freshwater and estuaries. Restricting themselves to waters of 15°C or less in the ocean appears to be a matter of preference rather than a physiological necessity. A temperature of 18°C, for example is considered the upper limit for cage culture in New Zealand (Kennedy, 1987). Brett et al. (1982) reported that, on maxiumum daily rations, optimum temperature for growth of chinook salmon was 19°C, above which feeding and growth rapidly decreased. The chinook stock held in Victoria produce viable ova at temperatures as high as 22°C (Rogan, 1981).

[3] After leaving fresh water, young chinook feed on the larger elements of the zooplankton (e.g., Healey, 1982); euphausids sometimes make up a major portion of their diet (e.g., Major et al., 1978).

Freshwater conditions

InNew Zealand and elsewhere it that it has provenbetter to concentrate initial sea-ranching efforts on a single river system than to stock several rivers simultaneously. We will identify, by process of elimination, what appear to be the best possible freshwater sites for sea ranching in Tasmania, rather than simply determining those sites where there appear to be no obvious impediments.

Temperature, oxygen and pH levels in most Tasmanian rivers for which there are data indicate that they are all generally well within the limits suitable for chinook growth (Alexander, 1987).

Within their natural range, chinook salmon tend to spawn in spring-fed tributaries of larger rivers (e.g. Unwin, 1986). They are not limited to such rivers, however, and will spawn in waters as shallow as 25 cm (Major et al., 1978). In New Zealand, moreover, the rivers in which chinooks have become established are far from typical of those they inhabit within their native range. Campbell (1980, p.44) states, "the New Zealand chinook is fighting the hostile, often unpredictable nature of our rivers and it suffers from flash floods, scouring, wandering streams, changing flow patterns, siltation and lack of vegetation, poor food supply and sometimes absence of estuaries to reduce the shock of changing from freshwater to salt."

Chinook can thus adapt to wide-ranging and less-than-ideal riverine conditions. Possibly their tendency to occur mainly in large rivers in North America is the result of competition for riverine habitat with the four other Pacific salmon species whose ranges overlap theirs.

The production of sea-ranched salmon is, of course, not limited by natural spawning and smolt-rearing habitat, but it does rely on abundant and reliable year-round supplies of fresh water. This consideration tends to narrow the choice of site for a chinook sea-ranching facility in Tasmania to the Huon or Derwent rivers; they are larger than any of the rivers entering Macquarie Harbour and the Port Davey–Bathurst Harbour area.

The Huon and Derwent Rivers area

Other considerations lend added weight to designating the Huon and Derwent Rivers area as the best location for sea ranching of chinook salmon. The area contains the largest concentration of people in the state[4] and is accessible by road at numerous spots. The area is thus also the best in the state for the parallel establishment of a recreational fishery for chinook salmon (see below).

In contrast, the Port Davey–Bathhurst Harbour area is almost uninhabited, is not accessible by road, and is not readily accessible to small boats because of the rough seas often encountered in getting there. By air it can only be reached by seaplane or helicopter. The waters of this area and of Macquarie Harbour are both comparatively poorly flushed, and are deeply stained with tannins which greatly restrict light penetration.

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[4]Industrial pollution in parts of this area should not prove an impediment. Chinook cannot be reared successfully in polluted waters, but they pass through such waters successfully on their migrations For example, Donaldson and Joyner (1983) state: "the chinook salmon brought to the university [of Washington] had to adjust to an environment far different from the environments commonly frequented by this species. . . . chinooks coming from the sea to their 'home' at the university must enter Puget Sound, turn left, enter the Lake Washington ship canal and pass through the locks either with the ship traffic or by way of the fish ladder along the south bank. Then, after a three-and-a-half mile trip through the congested industrial area along the shores of Lake Union, they must turn left again, climb a small ladder and enter a collecting pond on the campus." Considerable industrial and domestic pollution exists in both Puget Sound and the Lower Straits of Georgia, the world's two best areas for recreational fishing for this species. Both are situated near population and industrial centres much larger than the Hobart area.

Both factors may result in lower biological productivity[5] than that of the well-flushed waters in the vicinity of the Derwent and Huon Rivers, although this remains to be determined.

Damming of the Derwent River for production of hydro-electric power[6] has reduced the effective natural spawning area that would be available to chinook if natural runs were to supplement sea ranching (see below). But several significant tributaries enter the river downstream of the lowermost dam.

The use of gillnets or "graballs" would probably have to be strictly controlled in certain sheltered marine and estuarine waters if private interests were to be encouraged to invest in sea ranching in the state. It is likely that it could be much more readily controlled in this heavily populated area than in the other two large estuarine areas in Tasmania mentioned above

Release and Harvest Sites

Moe and Wing (1985, p. 25) state, "To minimize mortality of downstream migrating smolts and obtain maximum value from the returning adults, many ocean ranches in North America have moved release sites from traditional upstream locations to river mouths, to estuaries, or directly to open sea. Returning adults enter recapture facilities in near-prime condition, with high quality meat and a silvery bright appearance, and up to 90% of the total fish harvested can be sold as top quality product." Chinook can be made to imprint when being held in a seawater enclosure to which they return after one or more years at sea (Leet et al., 1986).

The Recreational Fishery

The successful sea ranching of chinook salmon in Tasmania would inevitably generate strong public pressure for the establishment of a recreational fishery. Moreover, a successful recreational fishery for the species could generate considerable additional revenue for the state.

It is also almost inevitable that some ranched fish on their spawning runs would stray and spawn naturally in non-natal rivers or streams. This could generate self-sustaining salmon runs in waters other than those initially targetted by sea ranchers.

Along the west coast of North America, from northern California to Alaska, chinook salmon are sought by recreational fishermen mostly in sheltered marine bays and straits, but also in rivers. The most common fishing methods are trolling, bait-casting or spinning from small boats. The terminal tackle that has evolved for chinook fishermen is specific to this species and can be quite elaborate (see Matsen, 1987a,b and Haw, 1985 for detailed descriptions of chinook lures and the associated trade). Chinook are occasionally caught by trolling a large fly.

At the height of the sports fishery for chinook and coho salmon in Puget Sound, Washington (an area of sheltered waters similar in size to those in the vicinity of Hobart) 208,000 chinook salmon were caught, as well as a similar number of coho salmon (Novotny, 1980).

[5] Environmental surveys of these areas would be required to establish whether such differences are so large as to affect chinook survival and growth.

[6] In New Zealand, one company actually used the tailrace of a power station as its release/recapture site — and in so doing became the first private hatchery to achieve major returns (Kennedy, 1987).

The establishment of a recreational fishery for chinook salmon would clearly bring to Tasmania a new type of fishing — one that enjoys great popularity wherever chinook runs occur. It would provide a new incentive for out-out-state recreational fishermen to visit, not merely enhancing existing incentives. It could thus generate considerable revenue for the state.

A recreational fishery would also present sea ranchers with both problems and opportunities. Some of these will be discussed briefly in subsequent sections of this report.

Cage Culture

Because chinook salmon are amenable to cage culture, the availability of this fish in Tasmania would diversify the options for the existing sea cage industry. (Young chinook rapidly acquire a tolerance for waters of high salinity [Miller and Brannon, 1981], facilitating their early transfer to sea cages.)

In addition to raising fish to market size, growers might also raise fish in cages for eventual liberation; chinook salmon held in cages beyond the time of their normal migration to the sea have been found to remain in coastal waters and closer to their release point [Novotny, 1975]). Novotny (1980) states that at least 250,000 coho and/or chinook salmon are reared in net-pens each year in Puget Sound for delayed release. This activity is funded by the Washington State Department of Fisheries[7]. Chinook would also provide an alternative in Tasmania in case of disease, or (possibly) in case of falling prices for cage-farmed Atlantic salmon because of overproduction[8] (the latter prospect is a major worry for international producers of Atlantic salmon [e.g. Anonymous, 1986a; 1987a]).

Cage-rearing to maturity might also be necessary in the early years of a ranching/introduction progam to build up broodstock.

[7] The potential conflicts between sea ranchers and others who harvest their fish in public waters can be controlled, as it is in other countries, by appropriate regulations (see next chapter).

[8] Since Atlantic salmon and chinook salmon are clearly distinguished by buyers in some countries, such as Japan, chinook prices might not fall as fast as Atlantic salmon prices in response to a glut of the latter.

Some Other Considerations

The focus of this report, as stated earlier, is on the question of what species of salmonid appears to offer the most promise for sea ranching in Tasmania. It is not our intention here to present a thorough appraisal of the logistics of introducing a new species of salmonid to the state. But, so as not to give too simplistic a view of how the endeavour might be accomplished, some potential problems are discussed briefly here.

Environmental Impact

Increasing inter and intra-national transfer of aquatic species in this century has prompted an increasing awareness of the potential problems associated with introductions. These include:

- the introduction of diseases that could spread to other species
- the disruption of the native fish community through competiton or predation
- alteration of the environment by the introduced species leading to indirect disruption of the aquatic community

Diseases

Viral, bacterial and parasitic diseases can be a major problem in salmonids, especially when they are held at high densities in hatcheries and cages. In Norway, for example, diseases cost salmon farmers 110 million U.S. dollars in 1983 (Dale, Ownes and Stenseth, 1987). Tasmanian salmonid stocks are free of serious diseases. Maintenance of this status helps ensure healthy recreational and commercial stocks and gives Tasmanian salmonids an advantage in the export market. For this reason there is a total ban on importing live salmonids and their ova.

If chinook salmon were to be reintroduced to Tasmania, this ban would have to be lifted temporarily. The fish chosen to produce the ova for export would undergo exhaustive tests, as would their ova. After the eggs were imported they would have to undergo a rigorous protocol involving ova disinfection and subsequent quarantine, followed by frequent inspection of the hatchlings, all carried out in a recirculating water system. (This was the procedure used when Atlantic salmon were imported by Tasmania before their release for sea farming.)

The most convenient sources of chinook salmon are the stocks at the Snobs Creek hatchery and private hatcheries in Victoria — the only sources of this species in Australia. Importations from overseas would require lifting not only the state ban on importation of live salmonids, but also a similar Commonwealth ban.

Bacterial kidney disease was tentatively diagnosed on the basis of histological evidence in chinook salmon at Snobs Creek. However, subsequent examination of affected tissues failed to isolate this organism. Vibriosis has been the main problem at the Snobs Creek hatchery, but a vibriosis vaccine is now used (F. Hames, pers. comm.).

A viral disease of redfin perch broke out in New South Wales recently and has spread to rainbow trout in several New South Wales trout hatcheries. There is the possibility the disease could spread to the chinook salmon in neighbouring Victoria.

Interactions with other species

When salmonids were first introduced into Tasmania in the last century, their potential impact on indigenous fish communities and the environment was of little concern. It was the safety of the alien fish that was judged to be of first priority. Other aquatic species were seen not as being vulnerable to changes brought about by the introduction of salmonids, but as potential predators and competitors. Various mammals and even some freshwater insects were also implicated as potential predators.

The impact of introduced salmonids on Australian native fish is poorly studied. The overwhelmingly positive response to salmonid introductions throughout the world suggests that they have created few major problems. Nevertheless, ways in which salmonids might interact negatively with native species include predation, agonistic (aggressive) behavior, competition for food, and habitat alteration.

McKay (1984) argues that indigenous Australian fresh-water fish have evolved little from their ancient forms, suggesting that they have experienced little or no competition (although many are well adapted for harsh environments). He further suggests that low species diversity and limited capacity to inhabit a variety of niches among these fishes have left 'empty pockets' that are liable to be colonised readily by introduced species. The Australian freshwater habitat is therefore vulnerable, in theory, to colonisation by introduced species that have evolved a wider range of habitat preferences and superior competitive abilities as a result of competition in their native range.

However, only in the case of the mountain galaxid, *Galaxias olidus* (not present in Tasmania), is there clear evidence to suggest that the invasion of a salmonid (rainbow trout) in an Australian stream (in New South Wales), has brought about the decline of a native fish. The mechanisms remain unclear (Tilzey, 1976).

River blackfish appear to coexist with trout in Tasmanian waters. Although their diets overlap, direct competition is avoided because of their different habitat preferences: river blackfish occupy river pools and spawn in submerged hollow logs (Jackson, 1981). This author concludes that the pattern of decline in native species is due to both the impact of introduced species and man-made changes to the environment. He cites the decline of grayling in Tasmanian waters as an example[1].

It is impossible to predict with absolute confidence the impact that chinook might have on native freshwater fishes in Tasmania. However, there are several reasons for thinking they might have less impact than that of the trout already established here. Unlike these species, chinooks typically: (l) reside for a relatively short time in streams before migrating to estuaries and the sea; (2) feed primarily on aquatic and terrestrial insects, rather than other fishes[2] during their freshwater residence (e.g., Miller and Brannon, 198l; Sagar and Glova, 1987); (3) cease to feed when they return to freshwater to spawn; (4) invariably die after spawning. (The death of spawning salmon can actually enhance the biological productivity of low nutrient streams such as Tasmania's by releasing nutrients that stimulate plant growth [e.g. Richey et al., 1975]).

Efforts are currently underway to try to rebuild stocks of Tasmania's once productive whitebait fishery. What would be the impact of of chinook on whitebait stocks in marine and estuarine waters? Chinook diets often include fish during their marine and estuarine phases and it is quite likely that whitebait would form part of their diet in Tasmania.

[1] In New Zealand, which supports a similar freshwater fauna, the grayling, *Prototroctes oxyrhynchus*, went into rapid decline in the early 1870s and is now extinct. McDowall (1984) states that trout could have had something to do with this, but the early decline seems likely to have preceded the widespread distribution of trout.

[2] It is well known that Tasmanian sea-run brown trout migrate upstream in the spring to feed on mixed-species whitebait runs (IFC Newsletter, 13 (3), 1984). One of the species in this run, *Lovettia sealii*, is perhaps particularly vulnerable to depletion, because it has a one-year life cycle and low fecundity (P. Davies, pers. comm.).

But whitebait have never been important in the area proposed for chinook ranching. The great bulk of the whitebait fishery was carried out along the north coast of the state. Blackburn (1949, p. 155) states, "the southern fishery has never been important because the fish available at the principal fishing locality are excessively pigmented."

The sometimes disastrous consequences of the introduction of alien species is well known and widely publicised. Despite the very widespread introduction of salmonids, however, we know of no serious repercussions.

Genetics

Loss of genetic variability in a stock can result in a decrease in its ability to adapt to environmental conditions. Each batch of salmonid ova imported into Australia invariably represented a limited gene pool from the outset. The survivors became subject to additional selection pressures from the new environment and artificial propagation.

The new 'wild' habitat presumably selected individuals best able to adapt to it. In addition, selection pressures in the hatchery, whether intentional or not, and the use of a limited number of broodstock, may result in a "domesticated" stock. This may be favourable for a farming operation. But where the species is introduced into a novel and more complex habitat, such as the rivers and seas of Tasmania, loss of genetic variability may lessen the fish's ability to adapt and establish itself.

Reduction in genetic variability through inbreeding is clearly a threat to the 'fitness' of any species being propagated by means of a limited broodstock. Where the population of a single generation is severely reduced, a 'population bottleneck' is said to occur. Ryman and Stahl (1980) examined the consequences of inbreeding in hatchery stocks of brown trout and recommended that stock should not be founded or perpetuated with fewer than 30 parents of the least numerous sex in any generation.

The chinook salmon held at the Snobs Creek Hatchery and private hatcheries in Victoria are, as described earlier, the only Australian source of chinook salmon. They have been propagated there since 1966. Progress was slow in the early years and in one year, only one ripe male was available to service the entire population of females (Rogan, 1981). However, recent experiments conducted on this stock suggest that it has not suffered genetic homogeneity problems as a result of small broodstock numbers (Hames, pers. comm.).

There is a relatively high incidence of precocious males in the stock; these fish are small and of relatively little recreational or commercial value.

Legal and Public Policy Aspects

Laws and administrative regulations that define public policy for sea ranching vary greatly from place to place, and have been changing rapidly. Salmon released into public waters by private salmon ranchers are public property while they remain in public waters. If a government chooses to encourage private investment in sea ranching then it must devise regulations that reconcile these interests with those of common property recreational and commercial fisheries. McNeil (1980) provides an excellent discussion of the approaches various governments have taken to this problem.

Commercial By-Catch

In the waters of the west coast of Tasmania where chinook salmon would probably concentrate during their oceanic phase there is a small commercial trawl fishery. It is possible that salmon would be caught incidentally by these trawlers. In New Zealand in 1986/87, 67 tonnes of chinook salmon were caught incidentally by commercial trawlers (Petersen, 1987; Todd, 1987). Various measures have been introduced to reduce this problem, and the situtation there should be monitored by anyone contemplating sea ranching of chinook salmon in Tasmania. Trawlermen are banned from targeting salmon. As of 1988, any salmon taken accidentally at sea by trawlermen are to be landed with approved fish processors and then offered for sale by tender to licensees of salmon fish farms (Anon., 1988).

Other Problems

Although the ocean rancher's food costs are much lower overall than those of sea-cage farmers, fish being raised for release must be in excellent condition in order to compete successfully in nature. Thus artificial food quality should probably be higher and holding densities lower at the hatchery than those used for raising pen-reared fish. Thus greater costs will be incurrred producing the same weight of smolt for release as for smolt for pen culture (e.g. Field-Dodgson, 1986).

At present, seawater acclimatisation experiments are being carried out with Victoria's chinook salmon at Queenscliff Marine Science Laboratories. Mortality and growth retardation have affected the fish, although correctable technical problems are thought to be the major cause (F. Hames, pers. comm.).

Summary

After examining the potential for sea ranching in Tasmania of the five species of salmonids present in Australia, we conclude that chinook salmon is the most attractive candidate. The other four species either offer very little hope of success based on past experience in Tasmania and elsewhere, Atlantic salmon, steelhead, brook trout) or do not offer comparable economic or recreational advantages (brown trout).

It is not possible to guarantee that chinook salmon would adapt to Tasmanian conditions. But an examination of the biology and environmental requirements of the species, the success of its introduction in New Zealand, and the characteristics of southeast Tasmania's marine and freshwater environments suggest no obvious reasons why an *adequately supported* sea-ranching program would fail.

Several strategies available for exploiting chinook salmon commercially might complement conventional sea ranching. These include sea-cage farming as currently practised with Atlantic salmon, and sea-cage farming for ultimate release for sea ranching or supplying a recreational fishery. It is premature to suggest precisely which mix of these and other possible strategies would best suit Tasmania.

Based on chinook environmental preferences elsewhere, we conclude that the Derwent and Huon rivers area and adjacent sheltered estuarine and marine waters offer the best location in Tasmania for sea-ranching trials.

A successful chinook fishery could generate significant new sources of revenue from both commercial and recreational fishing. It could create a new type of fishing in Tasmania, provide new incentives to out-of-state recreational fishermen to visit the state and diversify the options available to farmers of Altantic salmon and sea-caged rainbow trout.

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