Inland Saline Aquaculture

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Aerial view of serial biological concentration system at Undera, north-central Victoria, showing saline groundwater evaporation and adjacent agroforestry plot. (Photo: G. Gooley)

A 20 m^3 floating fish cage in a saline groundwater evaporation basin. (Photo: G. Gooley)

Two 10 000 L recirculating tanks used for the evaulation of snapper culture in saline groundwater within polytunnels at Cookes Plains, SA, location of the Bedford Saline Groundwater Interception Project. (Photo: W. Hutchinson)

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Introduction

Barney Smith*

AUSTRALIA HAS enormous underground reserves of water, much of it saline. Across large areas of the country, groundwater constitutes a serious challenge for agriculture: rising water tables and increasing salt content contribute to a worrying loss of fertility, leading to reduced productivity and alienation of valuable farm land. On the other hand, these saline water reserves represent a potential opportunity for the development of inland aquaculture.

The concept of this workshop had its genesis in a proposal submitted to ACIAR by the secretary of the Aquaculture Committee of the Standing Committee on Fisheries and Aquaculture. This drew attention to the high level of interest in inland aquaculture, evidenced by a number of exploratory projects in the planning stages or in progress around Australia. It also raised the possibility of ACIAR-mediated research collaboration with developing countries, several of which face salinisation of farm land and which share a potential for inland aquaculture. Subsequent consultation with aquaculture researchers and managers from a number of state and national agencies indicated two areas of primary interest:

- the development of aquaculture as a component of an integrated agricultural production system that could optimise and maintain the long-term productivity of inland, salt-affected lands and waterways
- the use of inland saline groundwaters for the culture of marine fish and aquatic products.

The Perth workshop brought together selected specialists in aquaculture, soil and water scientists, and resource managers from all Australian states and territories, and representatives from the Fisheries Research and Development Corporation and the Cooperative Research Centre for Aquaculture, to discuss issues and priorities for research in these areas. This proved to be a particularly timely and productive exercise; the deliberations of the meeting benefited from the broad mix of skills, disciplines and experience of the participants. The workshop sessions covered key technical and environmental issues and tried to define major opportunities for and constraints on the development of inland saline aquaculture. Operational guidelines for environmentally sustainable production were drafted, and a preliminary list of priority research topics was produced. These outcomes provide a solid starting point for further action. The group recognised the need to maintain a national focus on future activities and the value of continuing the multidisciplinary perspective so evident at the workshop. To this end, participants agreed to form a National Working Group on Inland Saline Aquaculture to help coordinate action on research and development in this area.

The success of this ACIAR workshop owes much to the support received from many individuals and several sources, including supplementary funding from the Fisheries Research and Development Corporation and the Rural Industries Research and Development Corporation. Mr Chris Barlow of the Queensland Department of Primary Industries expertly coordinated the workshop, and Fisheries WA generously hosted it.

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Inland saline waters in Australia

Bob Nulsen*

SALINE WATERS in inland Australia occur as rivers, lakes and ground water. With few exceptions the rivers and lakes are ephemeral and thus unreliable as a water supply for aquaculture. The ground waters occur in major basins, such as the Great Artesian Basin, the Perth Basin and the Canning Basin, and in shallow aquifers, many of which have developed since the introduction of European-style agriculture.

Objective 1 of the Inland Saline Aquaculture Workshop was 'to review the current information on and potential role of mariculture in management systems for controlling saline ground waters'. The greatest adverse impact of saline ground waters is on agricultural land and water bodies, wildlife habitats, and remnant native vegetation that receive water from agricultural catchments. There are also considerable effects on many rural towns and on rural infrastructure such as roads, bridges and railway lines. In the Loddon and Campaspe catchments in Victoria, local councils spend at least $1.2 million per year on repairs and maintenance of roads and bridges because of salinity (ABARE, 1997).

Origin and nature of saline ground waters

Saline ground waters that increase land and stream salinity result from the replacement of perennial, deep-rooted natural vegetation with annual, shallow-rooted agricultural crops and pastures. On average, this change results in an additional recharge to ground waters of 5 to 25 mm a year. Depending on the characteristics of the aquifer, this additional recharge causes a net rise in the ground water levels of 50 to 1000 mm a year.

Most Australian regoliths (weathered material from the surface to the bedrock) have a significant storage of soluble salts. These salts are generally of marine origin, having been deposited over millennia by rain. For example, rainfall currently deposits about 40 kg/ha/yr in Bendigo, Victoria; about 18 kg/ha/yr at Merredin, WA; and 340 kg/ha/yr in Perth, WA. In inland areas, where drainage and leaching are poor, these salts have accumulated to levels exceeding 1000 t/ha in 20 to 40 m of regolith. The salts are stored in the soil water, very rarely in crystalline form. Because of the marine origin of the salts, many inland saline waters have ionic compositions not too different from sea water. As a result of agricultural practices, however, they can have elevated phosphate and nitrate levels.

Ground waters that cause salinity problems are not necessarily highly saline. Total salt concentrations of 3 g/L can quickly accumulate to toxic levels in the plant root zone. Most saline ground waters have concentrations of less than 35 g/L.

Extent of inland saline waters

The extent of salt-affected land in Australia is a reasonable surrogate measure of the extent of saline ground waters. It was estimated in 1996 that about 2.2 million ha of once-productive agricultural land was affected by salinity, some 70% of that in WA (Robertson, 1996). If there is no significant change in land use, it is predicted that the area will increase to 3.5 million ha by 2050 (Table 1).

If we assume that each hectare of saline land is fed by a catchment at least 10 times its area, we are dealing with a catchment area of some 22

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Table 1. Estimated area of salt-affected land in Australia (data from Robertson, 1996).

State	Area (ha) 1996	2050*
Western Australia	1 609 000	2 400 000
South Australia	401 000	600 000
Victoria	120 000	240 000
New South Wales	25 000	250 000
Tasmania	20 000	30 000
Queensland	10 000	35 000
Total	2 185 000	3 555 000

* Assumes no change in current land use

million ha. At a recharge rate of 5 to 25 mm a year, this gives a total recharge of between 1 and 5 billion m^3 a year. (Lake Argyle, which supplies the Ord irrigation area, has a capacity of 5.6 billion m^3.) Thus there is no shortage of saline ground water in inland Australia. But can it be obtained and used for aquaculture?

Variability of supply quantity and quality

Although there is a large total supply of saline water, individual sources and their aquifer yields are relatively small, and their quality and quantity are highly variable in both space and time. Table 2 shows the variation in water quality over a 6 km transect of a catchment near Merredin, WA (George and Frantom, 1990). Note that the quality varies both along the transect and at different depths in the aquifer. Although the salts responsible for land salinisation are largely of marine origin, there can be large deviations from the

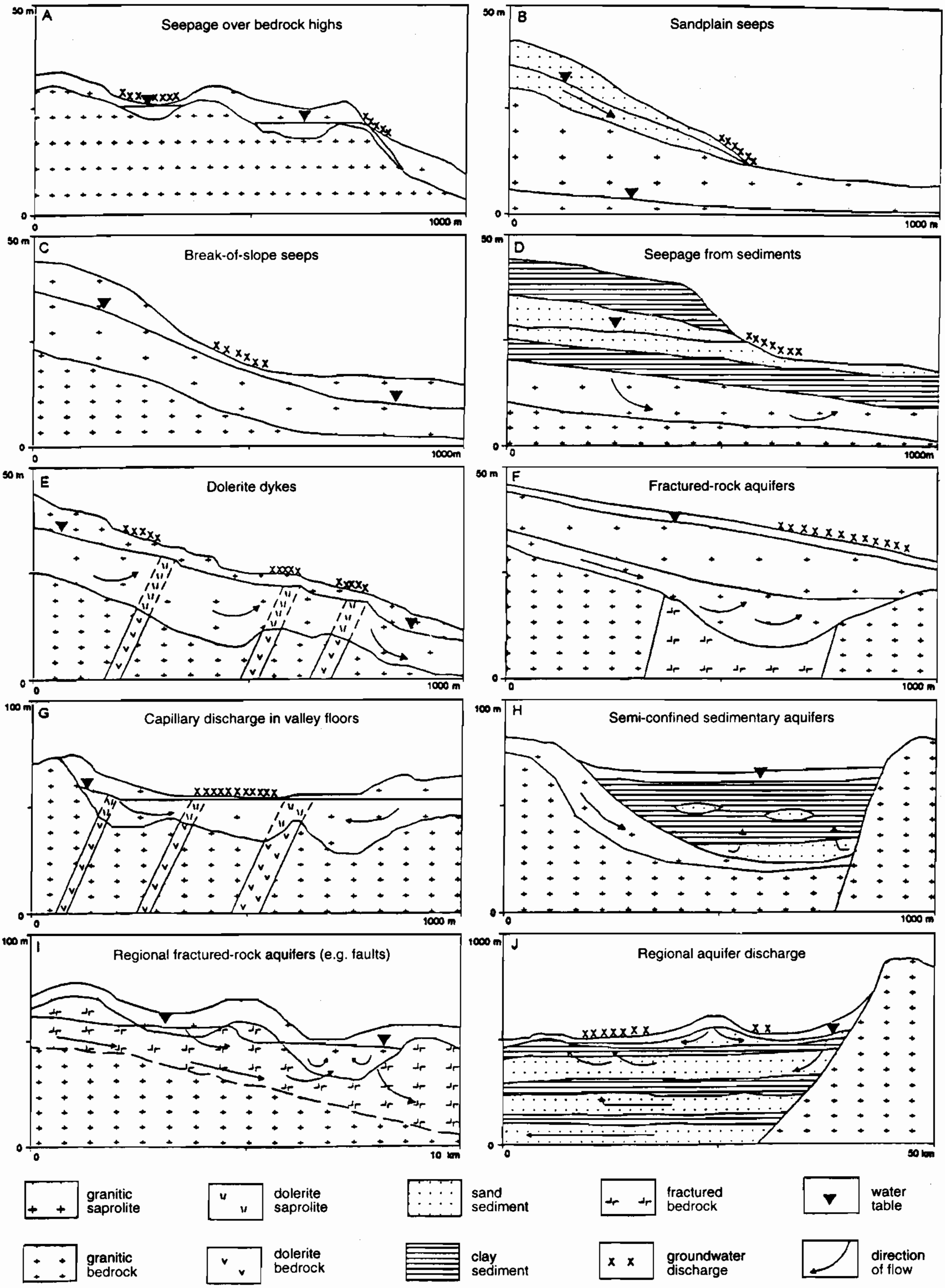
Figure 1 (over). Ten conceptual hydrogeological models that describe the occurrence of saline ground waters in the agricultural lands of WA. Models A to H have a length scale of 1000 m. Thus there is a high degree of spatial variability within a catchment, as several models can be applied to different parts of a catchment.

Table 2. Ionic composition (mg/L) of ground water along a 6 km transect in the Merredin catchment, WA. (Data from George and Frantom, 1990)

Bore	Depth (m)	pH	Total soluble solids	Ca	Mg	Na	K	Cl	SO_4	NO_3	SiO_2	Br
1	33	6.3	20 500	318	556	6 630	127	11 400	1 390	1	34	36
2	17	4.7	25 000	409	750	7 790	155	14 000	1 830	0	92	51
	45	6.3	15 600	508	442	4 710	89	8 700	1 000	0	30	28
3	9	4.4	32 000	452	895	10 300	202	17 800	2 310	3	56	56
	26	3.9	38 400	153	1 080	12 700	331	21 500	2 550	1	98	66
4	6	3.9	17 700	308	524	5 510	147	10 000	1 120	1	90	33
	19	6.1	3 070	28	35	1 030	26	1 360	401	1	57	5

Table 3. Ionic ratios of sea water and ground water in the Merredin catchment (data from George and Frantom, 1990).

Bore	Depth (m)	Cl:Ca	Cl:Mg	Cl:Na	Cl:K	$Cl:SO_4$	Cl:Br
Sea water		48	15	1.8	50	7	288
1	33	36	20	1.8	90	8	316
2	17	34	19	1.8	90	8	275
	45	17	20	1.8	98	9	311
3	9	39	20	1.7	90	8	318
D	26	150	20	1.7	65	8	326
4	6	32	20	1.8	69	9	303
	19	48	40	1.3	52	3	272


A
Seepage over bedrock highs
B
Sandplain seeps
C
Break-of-slope seeps
D
Seepage from sediments
E
Dolerite dykes
F
Fractured-rock aquifers
G
Capillary discharge in valley floors
H
Semi-confined sedimentary aquifers
I
Regional fractured-rock aquifers (e.g. faults)
J
Regional aquifer discharge
50 m
100 m
1000 m
0
1000 m
1000m
10 km
50 km
granitic saprolite
dolerite saprolite
sand sediment
fractured bedrock
water table
granitic bedrock
dolerite bedrock
clay sediment
groundwater discharge
direction of flow

marine ionic ratios over small distances and depths (Table 3).

The potential yield of an aquifer is dictated by its transmissivity, which is the product of the hydraulic conductivity and thickness of the aquifer. In some landscapes, thickness can vary by tens of metres in tens of metres. Similarly, the hydraulic conductivity can vary by orders of magnitude over short distances in geologically complex terrains. Quality variations in even small catchments can be large. For example, in a 77 ha catchment in South Australia the chloride concentration ranged from 2 to 8 g/L; in some bores it was increasing at 0.2 g/L/yr while in others it was decreasing at 1 g/L/yr (Henschke et al., 1994).

Hydrogeology of saline ground waters

Saline ground waters occur in a range of hydrogeological settings. The hydrogeology largely dictates the quantity, quality and accessibility of the saline water resource. For example, in Western Australia, ten conceptual hydrogeological models have been developed (Figure 1) (George et al. 1997). Being able to associate the correct model with the landscape enables prediction of the likely quantity and quality of the water and how it might best be reached. From a land management perspective the models indicate the type and placement of treatment that might be appropriate to ameliorate the salinity.

Sustainability of the ground water resource

In most catchments the size of the resource is still increasing (Fig. 2). However, if land managers apply appropriate treatments, the resource can diminish (Fig. 3).

So there is a potential conflict of interest between land managers who want to stop recharge to the ground water system and mariculturists who want to invest in a resource in the longer term.

Obtaining the ground water

Three options exist for obtaining ground water for saline aquaculture: pumping the water from the aquifer, draining the water from the aquifer, and excavating directly into the aquifer.

Pumping

In most catchments, shallow aquifers (< 30 m) can be found that will yield at least 20 m^3 a day when pumped. Modelling has shown that this extraction rate is often sufficient to reduce, or at least maintain, water table levels near the bore. The radius of effective water table draw-down is site-specific and is dictated not only by the transmissivity but also by the presence of any remnant

Figure 2. A typical hydrograph showing a steady rise in ground water levels.

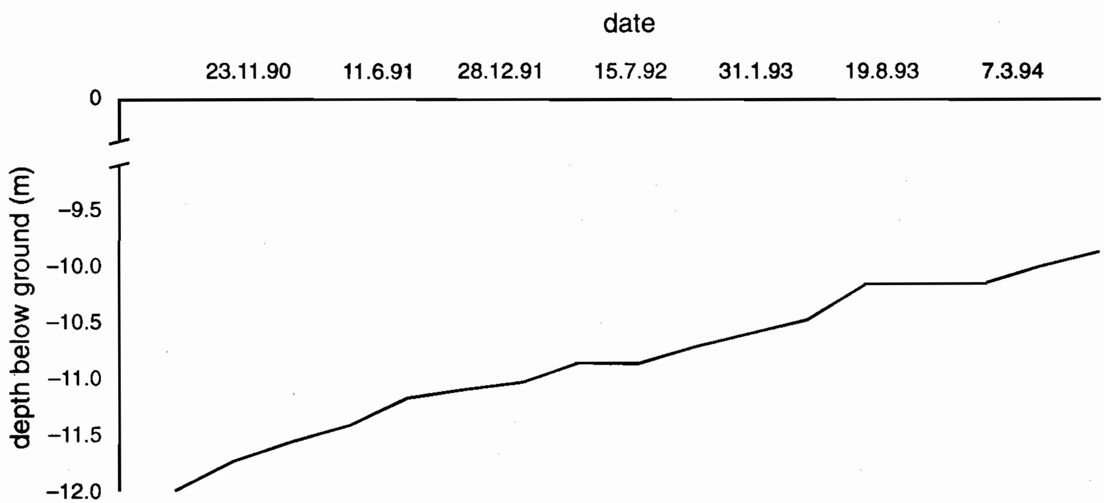
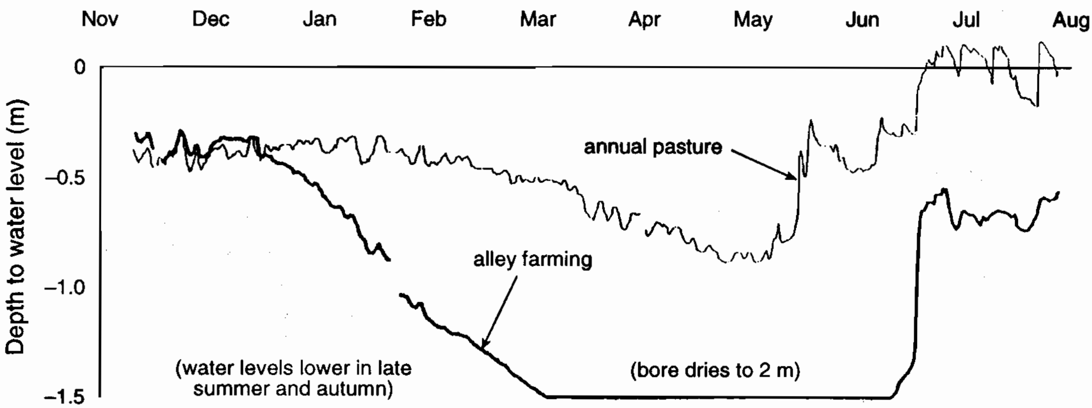


Figure 3. Hydrographs showing decline in ground water level under alley farming.



or extant geological structures such as dykes, shear zones and fractures.

Drainage

Drainage is restricted to drains about 2 m deep, and yields are variable. A 13.5-km-long drainage system in the sediments of the North Stirlings Basin in WA was yielding 170 m^3 a day 12 years after construction (Ferdowsian et al., 1997). Other drainage systems have ceased to flow, except in the wet season, after 1 or 2 years. So the supply from drains is not necessarily reliable.

The North Stirlings drain is in a 2200 ha catchment with a high salt storage of about 135 t/ha/m. When the drains were installed in 1984–86 there was 224 ha of saline land. By 1996 this had been reduced by 27 ha, of which 8 ha was croppable (the other 19 ha was too close to the drain to crop). A net present value analysis indicated that 40 ha would need to be reclaimed to cropping to break even over 20 years (drains $30 000; growing barley with a gross margin of $130/ha and a discount rate of 8%). Alternatively, an enterprise such as mariculture that gave an annual net return of $3600 would also make the system break even over 20 years.

Direct excavation

Direct excavation into the water table presumes that there will be no lowering of the water table. The flow rate through the system must exceed the evaporation rate to prevent salt accumulation. With the very low hydraulic gradients in most valley floors, where direct excavation is an option, the flow rate will be low and salt will accumulate unless good management is used.

Environmental constraints

Disposal of water extracted from aquifers must be environmentally benign. Evaporation basins, if they don't leak or overflow, are relatively benign, and the increasing salinity in them could be used by a sequence of saline aquaculture species. However, the eventual result is salt or extremely salty water.

Disposal of saline waters can cause significant downstream problems. The water can infiltrate into the soil and recharge downstream aquifers; thus we shift the problem from one area to another and there is no net gain. Saline water entering streams or wetlands can obviously affect their ecology. Even putting fresher water into naturally saline water bodies can have undesirable ecological effects on ecosystems adapted to saline environments.

Potential effects of saline aquaculture on land and stream salinity

Opportunities for large-scale saline aquaculture using saline ground waters appear limited. Similarly, the use of saline ground water for aquaculture is likely to have little effect on the extent of land and stream salinity. There may be small-scale opportunities for farmers to diversify their income sources and use the income generated to offset the costs of other remedial measures for land salinisation.

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An overview of the extent and nature of land and water salinisation in Asia

I. R. Willett*

THE EXTENT OF salinisation of inland water and land resources in Asia can be most readily estimated from the areas of salinised land in particular countries. Salinisation is generally associated with the development of irrigation areas. Table 1 indicates that the Asian countries most affected by salinisation are China, India, Pakistan, Iran and Thailand. The table underestimates the total area of salt-affected land, particularly for Australia and Thailand, as areas of dryland salinity are not included.

Table 1. Estimates of irrigated areas and the extent of salinisation in the most affected countries. (From Ghassemi et al. 1995, *Salinisation of Land and Water Resources*, UNSW Press, Sydney)

Country	Irrigated area (million ha)	% salt-affected
China	44.8	15
India	42.1	17
former USSR	20.5	18
USA	18.1	23
Pakistan	16.5	26
Iran	5.7	30
Thailand	4.0	10
Egypt	2.7	33
Australia	1.8	9
Argentina	1.7	34
South Africa	1.1	9

China, India, Pakistan and Thailand are important collaborators with ACIAR. As it has always been ACIAR's approach to base its research where it will have the greatest results, ACIAR can be expected to show strong preference for locating research projects related to salinity in these countries.

China has extensive areas of inland salinisation in its north, where about 15% of its 44.8 million ha of irrigated land is degraded by salinity. Inland southern China is not salinised. In the north-east, natural salt deposits result in saline rivers draining from the Minngan Mountains. Some of the rivers flow westward (inland) and cause salinisation in the Inner Mongolian steppes. To the south and east of Beijing large areas of the North China Plain are subjected to salinisation caused by shallow water tables and the use of ground water for irrigation. The semi-arid desert region of the upper Yellow River has large areas with sulfate-rich ground waters and surface salinisation where the land is irrigated. The far west of the country has ephemeral rivers that drain inland to the Gobi Desert, and there are numerous saline lakes, often high in nitrate and borate, in the remote highland areas of the Qinghai–Tibet Plateau. In general the salinised areas of China have cold winters and highly seasonal rainfall with summer maxima, and range from semi-humid to arid. The most prospective areas for inland saline aquaculture would appear to the intensely cultivated areas of the north-east and North China Plain. Ground waters are frequently of poor quality for irrigation (> 2 g/L total dissolved salts), but this is relatively low in comparison with marine salinity. The North China Plain frequently suffers summer flooding with fresh water (< 0.45 g/L), and marked seasonal changes in the salinity would be expected.

Inland salinity in **Thailand** is located in the Khorat basin in the north-east of the country. Surface expressions of salinity are associated with large-scale groundwater systems in contact with saline strata, including halite domes. In addition,

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secondary salinisation occurs because of excess recharge in upland areas after forest clearing, in a manner analogous to secondary salinisation in dryland areas of Australia. Salt-making activities by villagers have also exposed groundwater salt at the surface, but this has been discouraged and confined to larger operations that do not discharge salt to surface waters. Numerous small reservoirs have been dug, and some of these have shown trends of increasing salinity from the inflow of saline ground water. Some have reached salinities of 16 g/L. Inland saline aquaculture could be feasible in existing salinised water bodies and, perhaps, in association with salt-making. The strongly seasonal rainfall can be expected to cause seasonal variation in salt concentrations.

Pakistan has the world's largest irrigation system, based on the Indus River system. The area is subject to widespread waterlogging, sodicity and salinity. Some 5.8 million ha of land are salt-affected. Surface water quality is generally good for irrigation (0.15 to 0.47 g/L), but excess irrigation with inadequate drainage has resulted in surface salinisation. Surface water salinity varies widely according to location in relation to discharges of ground water, and during the season. Surface water salinity is diluted during monsoonal rains and by snow melt in the north. The river system has little artificial regulation, there are few surface storages, and evaporation ponds are not used. Ground water pumping is common for vertical drainage and to increase water supplies in the tail ends of irrigation schemes. Ground water salinity is extensive and generally increases from north to south and with depth. Salt concentrations are typically around 3 g/L, but higher concentrations are available at depth. Saline ground water may be diluted with fresher surface water and used for irrigation. Ground water with salt concentrations greater than 5 g/L is avoided where possible.

India also has extensive salinisation, having about 7 million ha of salinised land. Salinisation is extensive in the Indus–Ganga plains of north-western India and in the states of Haryana, Punjab, Rajasthan and Gujarat. The western part of this area (Rajasthan) is arid, and the rivers are intermittent. Smaller but significant occurrences are found in irrigation areas in southern India. Surface water quality in north-western India is generally good, but ground water quality is variable. Water salinity generally increases from north to south and with depth. Very saline water (16 g/L) can be found below 200 m.

Ground waters of sufficient salinity for inland saline aquaculture are available in each country discussed, and in very large supply in waterlogged areas on deep alluvium in Pakistan, north-western India and the North China Plain. When pumped for vertical drainage or to supplement surface water supply, the water is discharged to surface drainage systems; evaporation ponds are rarely used in Asia. The extraction of saline (> 3 g/L) ground water is undesirable because of its contribution to downstream salinisation of surface water. Inland saline aquaculture could provide additional income by using water associated with lowering water tables, increasing water supplies or salt-mining, but from an agricultural and resource management point of view it appears too risky to encourage deliberate extraction of saline ground water in inland areas solely for aquaculture.

Inland saline aquaculture activities in NSW

Geoff L. Allan* and D. Stewart Fielder*

ALTHOUGH THERE ARE no large, inland saline lakes in NSW, approximately 20% of the total Australian brackish and saline groundwater resources are found there (Ruello 1996). There are more than 50 000 licensed bores, and groundwater provides the single largest source of water in NSW (Ruello 1996). The 2 largest underground basins are the Great Artesian Basin in the north and the Murray Basin in the south.

Water from the Great Artesian Basin is available in many regions in northern NSW. In Moree, low-salinity alkaline water is discharged at 41°C, but water at higher temperatures is drawn in other areas (e.g. 98°C at Birdsville). Salinity is predominantly from sodium salts. The water is abundant and costs an estimated $1.50/ML (Ruello 1996).

Murray Valley Irrigation Ltd manages a large saline water resource primarily to control and remove salt from land used for agriculture. The company controls approximately 1600 ha in approximately 30 basins (Ruello 1996). Salts are mainly sodium chloride, but magnesium chloride and calcium sulphate are also present (Ruello 1996). Approximately 13 000 ML/yr is pumped into large holding basins and then into smaller, shallower evaporation ponds. Water from the bore is at a fairly constant 22°C, although the temperature can vary depending on depth and water flow (Ruello 1996). It costs an estimated $0.30/ML (Ruello 1996). Table 1 shows the composition of this ground water and sea water.

The first commercial aquaculture operation to rely on saline groundwater was established in NSW in 1991 at Grong Grong (near Narrandera) to farm barramundi. This operation pumps saline groundwater from approximately 177 m. Salinity is approximately 25 g/L (Table 1). The farm produces up to 18 t/yr of high-quality barramundi (pers. comm. B. Gawne, Barraclear, Grong Grong, 1997).

Table 1. Composition (g/L) of sea water and of ground water at 3 locations in the Murray basin.

	Sea water[a]	Wakool Stage 1[b]	Wakool Stage 2[c]	Grong Grong[d]
Cl	19.640	7.343	19.700	11.418
Na	10.860	3.410	9.150	6.200
SO_4	2.700	1.553	1.910	1.200
Mg	1.340	0.623	1.680	0.027
Ca	0.370	0.365	1.230	1.500
K	0.310	0.049	0.081	0.050
HCO_3	0.150	0.182	0.209	0.133
PO_4	0.008			
Salinity	35	14	34	25
pH	8.2	6.9	7.7	7.1

a. Spotte (1979)

b. Analysis of solutions from evaporation basins, June 1985 (pers. comm. W. Percival, Murray Irrigation, Wakool, 1997)

c. Analysis of solutions from evaporation basin, October 1987 (pers. comm. W. Percival, 1997)

d. Analysis of solutions from bore, September 1991 (pers. comm. B. Gawne, Barraclear, Grong Grong, 1997)

A second, much more preliminary trial with saline groundwater is under way near Maitland. Here, a local turf farmer has constructed a 0.1 ha earthen pond and filled it with groundwater of approximately 23 g/L salinity. Australian bass and mulloway have been stocked, and both species

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have survived and grown for 5 to 6 months. Both operations currently have permits for farming fish in NSW.

NSW Fisheries scientists are about to embark on a collaborative project through the Aquaculture Cooperative Research Centre. The project will involve a number of commercial fish farmers and industry and government partners and will investigate the use of saline groundwater in snapper culture. In NSW, research will involve evaporation ponds at Deniliquin (part of the Murray–Darling drainage basin) and the commercial fish farm at Grong Grong.

Collaborative experiments with scientists from the South Australian Research and Development Institute will take place in a commercial recirculation tank in a solar polytunnel at Meningie, SA. Initially water from different sites will be taken to the Port Stephens Research Centre (PSRC) and used in static experiments to determine the growth and survival of juvenile snapper at different salinities (15–50 g/L, diluted where necessary with rain water from PSRC). Following this, in-situ experiments will be carried out in cages in an earthen pond at Deniliquin and in large indoor recirculation tanks at Grong Grong and Meningie. If the experiments are successful, work to optimise culture of snapper will continue. Mulloway bred at PSRC will also be evaluated as time and resources permit.

Inland saline aquaculture is an attractive prospect in NSW. Abundant water resources are available, preliminary trials with temperate fish are encouraging, and a commercial operation using saline groundwater has been operating successfully for several years. Current research will evaluate saline water from fish culture in existing evaporation ponds and in purpose-built, indoor, intensive fish-farming facilities. If the first option is successful, capital costs for constructing fish farms will be very low.

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Inland saline aquaculture—a Victorian perspective

Geoff Gooley*, Brett Ingram* and Lachlan McKinnon*

Inland saline water in Victoria—the resource

Surface waters (inland lakes and coastal embayments)

Permanent saline lakes are typically limited in extent, although notable examples include Lake Corangamite (23 000 ha; 30–35 g/L total dissolved solids, or TDS), an effectively closed, naturally saline drainage system in south-western Victoria, and a number of smaller, modified saline lakes within the Goulburn–Murray Irrigation District (GMID) in north-western Victoria. The most significant coastal embayment that fits loosely into the definition of inland saline waters is the Gippsland Lakes (400 km^2; 0–36 g/L TDS; av. 15–16 g/L TDS mid water-surface). Features that often characterise inland saline surface waters include variable water quality (often tending towards eutrophication), high environmental value (often significant wetlands) and their shallow, ephemeral nature (particularly in the west and north-west of Victoria).

Ground waters (shallow and deep aquifers)

In contrast to surface waters, saline ground water reserves (both shallow and deep aquifers) are relatively extensive. These reserves are mostly concentrated in the western, south-western, north-central and north-western areas of the state, in association with areas of major dryland and irrigated agricultural development within the Murray basin and in the semi-arid areas of the Wimmera and Mallee regions. Within the Murray basin, shallow (< 15 m) saline aquifers (> 1.8 g/L) tend to be concentrated towards the lower reaches of their catchments, whereas the deep saline aquifers are mostly restricted to the Wimmera–Mallee. Table 1 summarises the salinity, yield,

Table 1. Characteristics of the ground water basins of Victoria.

Basin	No. bores	Salinity range (g/L TDS)	Range of bore yields (L/sec)	Divertible volume (ML/year)	Ground water uses (Irrigation, Stock watering, Domestic supply, Urban supply)
Gippsland	6 000	< 0.5–2.5	<2–150	325 000	45% for ISDU and coal face stability
Highlands Province	8 000	0.1–10	0.1–125	100 000	19% for ISD and commercial sale (mineral water); mostly unused
Murray	10 000	< 0.5–40	2–125	240 000	80% for ISDU and salinity control
Otway	14 000	0.1–8	0.1–115	300 000	9% for ISDU; mostly unused
Port Phillip	4 000	0.1–8	< 0.2–40	10 000	80% for ISD, golf courses and salt production
Western Port	5 000	0.3–5	2–40	25 000	40% for ISD

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volume and use of the extensive network of existing bores in Victoria.

The shallow aquifers are mostly readily accessible, particularly in irrigation areas with high water tables, and are often supported by extensive infrastructure, including pumps, reticulation systems and holding basins. Water temperatures typically reflect close-to-ambient conditions, and water quality is often highly variable. Apart from high salt concentrations, the risk of nutrient enrichment and pesticide residues in shallow aquifers is an issue.

In the GMID, rising water tables are a major problem for irrigated farm production. Saline ground water being pumped from these aquifers is generally disposed of through community drains (subject to state salt credits as measured at Morgan in South Australia) or to evaporation basins, or is reused (sometimes after being diluted with fresh irrigation water). The Goulburn Irrigation Area (GIA) alone pumps approximately 221 000 ML/yr of mostly saline water from 850 pumps to mitigate the effect of rising water tables and associated salinity. Closed evaporation basins (up to several hectares in surface area) are being developed as a more environmentally sustainable disposal option. Indeed, more than 50 basins are proposed to be constructed in the GIA within the next decade.

The abundant, deep, saline aquifer reserves are largely unexploited but are generally thought to be relatively high quality, high yielding and warmer than ambient in many areas.

Inland saline aquaculture—the activity

Opportunities for use of inland saline water resources for commercial aquaculture have been identified within Victoria, primarily as a means of offsetting the costs of salinity effects and associated mitigation costs, but also as a means of increasing inland aquaculture production. Several research projects are being done by the Marine and Freshwater Resources Institute (MAFRI) as part of an initiative to integrate aquaculture and agriculture. The main aims of this initiative are multiple water use, on-farm diversification, use of existing infrastructure, application of cage culture techniques, and increasing overall farm productivity (as opposed to production of any one species).

The largest project, the Inland Mariculture Scoping Study, is funded by Fisheries Victoria (Victorian Department of Natural Resources and Environment) and the Natural Resources Management Strategy of the Murray–Darling Basin Commission, and is being done in collaboration with Agriculture Victoria (DNRE). The main objectives are:

- to investigate small-scale, on-farm, saline aquaculture production in evaporation basins as part of a serial biological concentration system (SBCS) within the GMID
- to evaluate the suitability of potential aquatic species for commercial production in such systems
- to characterise key water quality parameters in such systems.

The strategy involves cage culture of a range of euryhaline species (species able to tolerate a wide range of salinities) in each of 2 ponds supplied with pumped water from a shallow aquifer at differing salinities (10–15 g/L and 15–25 g/L). The pumped water is first used to irrigate an agroforestry plot consisting of some 20 varieties of salt-tolerant poplars and native trees, shrubs and grasses, after which the residual leached water increases in salinity and is collected by subsurface tile drains and pumped into the evaporation basin. Table 2 summarises the ionic composition of the 2 ponds. Progress to date indicates that silver perch, Australian bass and Atlantic salmon have given the best performance, and that temperature and salinity are the principal determinants of growth and survival. The ionic composition and natural productivity of the ponds are also thought to have had an effect on some species. Staff from the Tatura Institute of Sustainable Irrigated Agriculture (Agriculture Victoria) are evaluating the SBCS and associated agroforestry trials.

Other MAFRI research projects are currently in progress:

- Use of low-conductivity (approx. 1–2 g/L TDS) ground water being diverted through fish tanks stocked with silver perch before being re-

Table 2. Concentrations of the major ions (g/L) at 3 locations at the Inland Mariculture Site, Undera (GMID), compared with those in seawater at corresponding salinities, 2 June 1997. Salinities are given in column heads.

Ion	Inlet (10 g/L)	Pond 1 (10 g/L)	Seawater (10 g/L)*	Pond 2 (18 g/L)	Seawater (18 g/L)*
Cl	4.13	4.20	5.53	7.96	11.0
F	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
SO_4	1.28	1.30	0.775	2.15	1.55
Br	< 0.001	< 0.001	0.019	< 0.001	0.038
HCO_3	0.190	0.170	0.041	0.170	0.081
B	0.001	0.001	0.001	0.018	0.003
Ca	0.350	0.320	0.118	0.560	0.235
K	0.025	0.025	0.114	0.045	0.228
Mg	0.470	0.500	0.370	0.900	0.739
Na	2.70	2.70	3.08	4.90	6.16
Sr	0.005	0.004	0.002	0.007	0.005

* From Riley and Skirrow (1975).

directed back onto an existing agroforestry plot. (Funded by Fisheries Victoria and the Rural Industries Research and Development Corporation.)

- The production of cage-cultured silver perch and rainbow trout in a saline lake in the GMID (Lake Cooper; 1100 ha surface area; approx. 3 g/L TDS). This is being investigated in an attempt to enhance fisheries production from existing Victorian lakes and reservoirs. (Collaborative study with Deakin University and funded by Fisheries Victoria and ACIAR.)

At least one commercial operation, based at Pyramid Hill in north-central Victoria, is also investigating commercial aquaculture in saline ponds supplied from an adjacent shallow aquifer. The main objective is salt production, but the operation has also grown *Artemia* for the aquarium trade. Approximately 300 GL/yr is pumped from about 12 m depth at a constant temperature of 18°C and a salinity of 33 g/L.

General observations

In general, evaporation basins supplied from shallow aquifers within existing irrigation areas appear to have potential for economically viable commercial cage culture of some species in the GMID, at least on a seasonal basis. However, such production would need to be integrated into existing farming operations in order to be cost-effective. Socioeconomic benefits are likely to include increased revenue and the opportunity for all family members to participate in on-farm production. Although the irrigation industry has been receptive to date, access to training and education services will be critical to long-term viability.

Cage culture may also be suitable for semi-intensive aquaculture in saline lakes, whereas deep saline aquifers are likely to be most suitable for purpose-built aquaculture production in the semi-arid areas of Victoria. Water quality for the latter option is likely to be more consistent and perhaps at higher-than-ambient temperatures, but saline effluent would still need to be directed to evaporation basins or reinjected back into the aquifer.

Future direction

Inland saline aquaculture trials in the GMID are currently in their third and final year and are now being done as a commercial-scale pilot using the 'best' species under 'optimal' conditions. Other proposed tasks include the development of a conceptual nutrient mass balance model for the basin, an economic cost–benefit analysis, taste panel appraisal of the produce, and the development of management guidelines and associated policy to define the conceptual framework for industry development. Technology transfer and associated training and education requirements will be needed.

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Inland saline aquaculture in South Australia

Wayne Hutchinson*

In a number of agricultural areas of South Australia, shallow saline ground water has reduced the quality of irrigation and municipal water supplies and has degraded arable land. Aquaculture is being investigated as a means of reducing the problem or deriving an income from use of the problematic saline ground water.

In SA there are currently no commercial aquaculture operations that use saline ground water, although some developments are planned or are at the research stage. As in other states, saline water for inland aquaculture can be supplied from surface water, shallow aquifers and deep aquifers. These water sources offer a number of options that could be be suitable for the production of aquatic organisms (Table 1), although the economics of production are yet to be established.

Table 1. Types of production systems to be evaluated for inland saline aquaculture in SA.

Water source	Level of production		
	Extensive	Semi-intensive	Intensive
Saline surface water bodies	• Stock and harvest with no additional feeding • Stock and harvest as 'put and take' recreational fishing attraction	• Stock and harvest with additional feeding	• Floating cage culture
Shallow aquifers	• Pond culture at low stocking density with no additional feeding • Integrated 'polyculture' systems at low stocking density	• Pond, tank or raceway culture at moderate stocking density • Integrated 'polyculture' systems at moderate stocking density	• Pond, tank or raceway culture at high stocking density • High-density culture in polytunnel-type structures
Deep aquifers		• Pond, tank or raceway culture at moderate stocking density • Integrated 'polyculture' systems at moderate stocking density	• Hatchery facilities • Pond, tank or raceway culture at high stocking density • High-density culture in recirculating systems

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Use of inland saline water bodies for aquaculture

Inland saline water bodies (e.g. Lake Eyre) are common in SA and are characterised by high productivity over a short duration. Because of conservation considerations, their ephemeral characteristics and their remoteness, they are not targeted for aquaculture use.

Salinity increases substantially along the course of the Murray River within SA. Between Overland Corner and Waikerie (Woolpunda Reach), a distance of approximately 30 km, saline ground water contributes 170 tonnes of salt a day, equivalent to 8% of the salt load in the river (SA E&WSD 1994a). In the next 20 km section a further 105 tonnes a day is added (SA E&WSD 1994b). To reduce this, the Woolpunda and Waikerie salt interception schemes have been implemented to divert intruding saline ground water to salt evaporation basins. Together these schemes use a total of 66 bores, 70–125 m deep, arranged in a line either side of the Murray to pump 32 ML of saline water each day by pipe to the Stockyard Plain disposal basin 15 km west-south-west of Waikerie. The salinity of water within the basin ranges from 10 to 35 g/L. The basin itself is recognised as a significant wetland site of 305 ha within a 1870 ha site. Forty-one waterbird species use it as a drought refuge, feeding area and loafing area, and it supports flora and fauna that normally live in marine environments (Blackley et al 1996).

Because of this established significance it would seem to be more appropriate to divert the incoming water to purpose-built aquaculture facilities before treating it and then discharging it into the Stockyard Plain disposal basin. This approach would also allow any aquaculture system to be managed more effectively.

A number of smaller basins along the Murray receive drainage water from irrigated land, but the variable supply and salinity and possible nutrient and chemical contamination are likely to make these basins unsuitable for the needs of aquaculture.

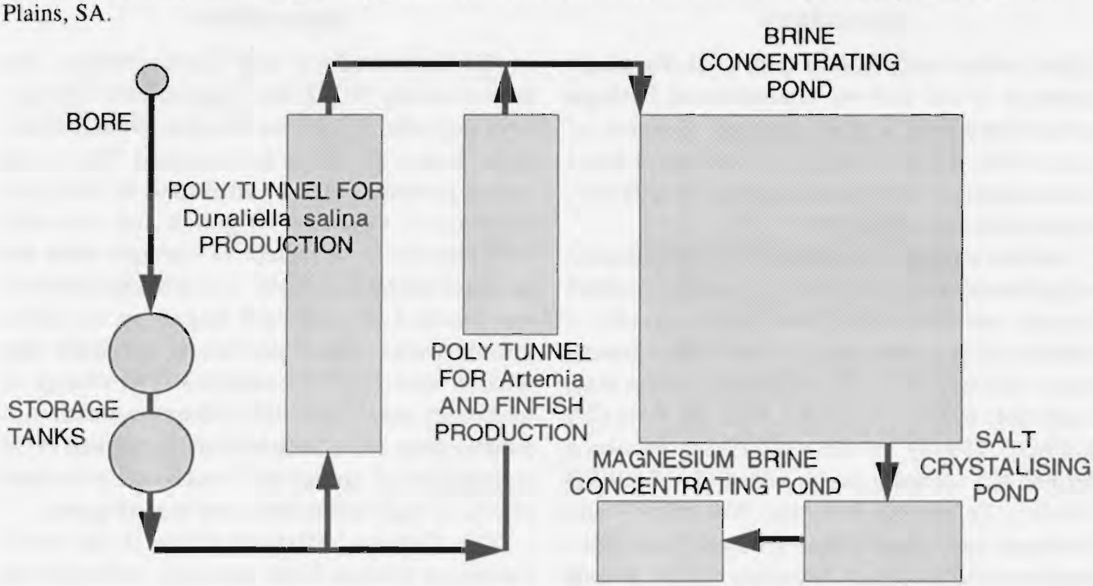
Use of shallow saline aquifers for aquaculture

In the Coomandook and Cooks Plains area approximately 30 000 ha of agricultural land has been degraded by the rise of saline ground water, and a further 30 000 ha is threatened. The rise in saline ground water is attributed to the containment of water for irrigation and domestic consumption by a system of barrages near the mouth of the Murray River. This artificial reservoir has blocked the seaward migration of saline ground water, which previously surfaced near what is now Lake Alexandrina. The change in hydrology combined with extensive clearing of natural, deep-rooted vegetation has resulted in the degradation of agricultural land by the combined effects of high soil salinity and waterlogging.

The Coorong District Council and local Landcare groups have recently initiated the Bedford Ground Water Interception Project, funded by the Rural Industries Research and Development Corporation, to develop ways of using saline ground water removed to lower the water table (Fig. 1). The project is investigating the potential of polytunnel technology for the culture of *Artemia*, *Dunaliella salina* (for beta carotene production) and finfish species. This would be part of a serial biological concentration process that would ultimately produce industrial salt and bittern (a bitter oily liquid) for road stabilisation. The production of these saleable products should help to offset the cost associated with pumping down the water table and may even return a profit.

The project uses 3 polytunnels (1 @ 46 m × 10 m, 2 @ 20 m × 10 m) supplied with saline water pumped from 1 m below the soil surface. Water is drawn from an open 2.0 m × 3.0 m pit through a geotextile-covered intake. Pumping 8000 L over 1 hour will drain the pit, which refills in approximately 5 hours (a recharge rate of 1600 L/hr). The salinity of the ground water varies from 27.2 g/L (SG = 1.020) to 33.7 g/L (SG = 1.025) at ambient temperature.

Figure 1. Schematic outline for components of the Bedford Groundwater Interception Project at Cookes Plains, SA.



The largest polytunnel houses a lined, 0.5-m-deep pond arranged in a continuous raceway configuration for *Dunaliella salina* production. Another polytunnel currently houses two 10 000 L fibreglass tanks and recirculation system components to assess the suitability of the saline water for the growth and survival of a range of finfish species. To date, tommy rough (*Arripis georgiannus*) has been stocked with no mortality. It is intended that black bream (*Acanthopagrus butcheri*), snapper (*Pagrus auratus*), greenbacked flounder (*Rhombosolea taparina*), King George whiting (*Sillaginodes punctata*), yellow-fin whiting (*Sillago schombergkii*) and mulloway (*Argyrosomus hololepidotus*) will also be trialed.

Use of deep saline aquifers

Deep saline aquifers offer a number of advantages to aquaculturists. If such water is available it usually contains a very low bacterial and viral load, and the water temperature is stable throughout the year. Salinity can be a problem, as it is site-specific; it can range from low (< 5 g/L) to hypersaline (> 40 g/L). The pH of saline bore water can be less than 7.4, which is regarded as a minimum acceptable level for aquaculture in seawater systems (Needham 1988), but this is generally easy to correct with vigorous aeration to remove residual CO_2 (Prickett 1996). Chemical analysis of deep saline water supplies commonly gives a chemical profile similar to that of sea water; in most cases such water sources are suitable for a range of saline aquaculture operations.

In SA, Fish Protech Developments Pty Ltd has used saline ground water to supply a number of land-based culture systems for grow-out of barramundi (*Lates calcarifer*) and silver perch (*Bidyanus bidyanus*). These systems have been sold under community title and are located at the Australian Aquaculture Technology Export Park at Pelican Point, near Port Adelaide. Earlier examples of these recirculating systems are also being used to culture barramundi at a similar aquaculture park at Kangarilla, south of Adelaide.

Each culture system uses 2 holding basins supported by a recirculating water treatment system. The treatment system uses biological and mechanical filtration to maintain optimum water quality. It is anticipated that local marine species such as snapper and King George whiting will be suitable for culture in these systems as fingerling supplies are established. The controlled environmental conditions may also provide the possibility for the culture of other marine species such as tropical snapper (*Lutjanus* sp.) and grouper (*Epinephilus* sp.).

At the Pelican Point site, water used in broodstock holding, hatchery and nursery facilities and in grow-out systems will be drawn from a saline aquifer at a depth of 520 m. This aquifer supplies water at 35 g/L salinity, a maximum flow of 25 L/sec (90 000 L/h), and a temperature of 40°C. Only 5.5 L/sec of this capacity will be used in the park. Salinity control will be achieved by adding low-salinity water (3 g/L at 27°C) taken from another deep aquifer and stormwater collected from the roofs of all buildings on-site.

All water used will be treated, contained and possibly reused on-site.The recirculation systems will exchange approximately 3% of the total volume per day. Effluent will be discharged into a sedimentation basin before being filtered and disinfected, and run into a saline wetland system.

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Inland saline aquaculture in Western Australia

Greg Paust*

THE DEVELOPMENT of inland saline aquaculture is one of a number of objectives of Western Australia's aquaculture development strategy.

Commercial inland aquaculture in WA is currently based on the production of yabby (*Cherax albidus*), marron (*Cherax tenuimanus*), trout (*Oncorhynchus mykiss*), barramundi (*Lates calcarifer*) and beta carotene from the alga *Dunaliella salina*. In terms of value, the largest sector is the production of beta carotene at Hutt Lagoon near Port Gregory, some 500 km north of Perth. This venture uses part of a salt lake system and supplements water requirements with sea water. The yabby, marron and trout industries were valued at about $2m, $0.5m and $0.5m respectively in 1996–97. The first significant production of barramundi will occur in 1997–98.

Following the success of the Fremantle Maritime Centre in developing hatchery technology for the euryhaline (able to tolerate a wide range of salinities) black bream (*Acanthopagrus butcheri*), several hundred thousand fish have been stocked in water bodies on farms for domestic or recreational use. The salinity of the water stocked ranges from freshwater farm dams to saline lakes and ponds. The apparent success of this species has resulted in considerable interest in its use for commercial saline aquaculture in inland waters in the south-west of WA. A recently established industry group, the South West Inland Fish Farmers Association, attracted 1600 visitors to a recent field day.

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Present and future development activities

Kimberley

Following the release of the Kimberley Aquaculture Development Plan, the Fisheries Department and the Kimberley Aquaculture Development Commission are preparing a strategy for the development of a significant aquaculture industry in the Kimberley region. The first focus of the work is Lake Argyle and the Ord River irrigation system. The objective is to develop a significant finfish industry in the area. There is also considerable interest in production of redclaw (*Cherax quadricarinatus*).

Preliminary assessment has been completed. Ground water reserves exist in the Kimberley, and the potential to use them to develop prawn and other fish production will be considered in the next few years. Further assessments of the technical, environmental and economic feasibility of developments are being done or planned.

Gascoyne

Following the release of the Gascoyne Aquaculture Development Plan, the Fisheries Department and the Gascoyne Development Commission established the Gascoyne Aquaculture Development Group to support aquaculture development in the region.

The group is investigating the potential for the use of the artesian bore waters of the region. Water temperatures range from about 35° to 60°C and salinity ranges from brackish to very saline. Following the completion of a feasibility study, the Aquaculture Development Fund has provided funds to identify the best sites for the establishment of a pilot production unit and to test the survival of barramundi juveniles in the water available at these sites. An investor will later be sought for a proposed pilot phase. Further assessments of the technical, environmental and economic feasibility of developments are being done or planned.

South-west

The agricultural region in the south-west of WA is facing significant land degradation problems. The main cause is salinisation of land as a result of rising water tables following the clearing of perennial vegetation for agriculture.

If sufficient saline ground and surface waters are available (of a quality suitable for economic fish production) and the bypass or effluent waters can be managed in an environmentally acceptable way, an opportunity may exist to develop saline aquaculture ventures. If suitable water and land resources are identified, the potential from a technical, economic and environmental point of view may be considered. The benefits sought include diversification opportunities for farmers and catchment benefits from aquifer draw-down. Another benefit could be the farming of species that normally would not be approved for marine culiture.

Future work is planned to identify the location of inland saline water supplies in the volume and quality necessary for saline aquaculture. In areas where sufficient water exists, the suitability for earthen pond construction will also be assessed.

Using serial biological concentration to combine irrigation and saline aquaculture in Australia

John Blackwell*

Irrigation

Irrigation is essential in meeting the basic food needs of billions of people. It grows more than half of the world's 2 most important basic staples (rice and wheat) and nearly a third of all food crops. In Australia, irrigated agriculture produces 25% of total agricultural production, worth $6–8000m a year, from 2 million hectares.

To keep pace with population increase, food production must also increase. One answer is to increase irrigation. However, most of the world's fresh water is already committed, and irrigation is responsible for salinisation and waterlogging of much irrigated land: Salinisation of land on a global scale is occurring at a rate of 1–2 million hectares a year (Umali 1993).

The scarcity of suitable water resources therefore necessitates other solutions, including better management of existing resources, the reuse of waste water, control of water pollutants, and the careful use of saline ground water.

This paper considers the potential of three sources of saline water in Australia for use in a serial concentration system that starts with irrigation and ends with salt production, with aquaculture as one of 5 intermediate stages.

Australian water resources

Total runoff in Australia amounts to 440 km^3 a year, of which 123 km^3 is potentially useable. The full extent of ground water is not known, but 2.46 km^3 is used each year for irrigation (66%), urban and industrial uses (20%) and stock watering (14%) (Jacobson 1983).

Australia has more than half a million water bores (Lau et al. 1987). Most are near Perth and Adelaide, throughout south-east SA, in WA, and along the central Queensland coast. In a large part of the country the ground water resource is underdeveloped, but in some areas supplies are being overdrawn (O'Driscoll 1979).

Overall, irrigation accounts for 80% of all water used in Australia.

There are 3 potential sources of 'natural' saline water in Australia: lakes, deep aquifers and shallow aquifers.

Saline lakes

Many Australian lakes are very shallow (1.5–2.0 m), and hence ephemeral, and this leads to wide fluctuations in salinity. In WA the salinity of these lakes is variable and is often 2–3 times that of sea water (pers. comm. D. R. Williamson, CSIRO Land and Water, Perth, 31.7.97). Depending on the location and quality of the source water they may have specific pollutant problems. They may also have specific ionic imbalances; for example, in selenium, fluoride, iron, lead or zinc.

Rising water tables in unconfined aquifers can cause seasonal lakes to become permanent.

Deep aquifers

Generally speaking (particularly in the Murray–Darling Basin), the deeper aquifers tend to be less salty than the shallower ones. However, as depth increases, so do the costs of drilling, installation, maintenance, pumping and running.

Ground water recharge is likely only in very wet years (when rainfall exceeds transpiration) and is often remote from discharge points. Most ground waters are very old; water moves very slowly through the aquifer (1–11 m laterally per year). The sustainable resource is equivalent to

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the throughflow under prevailing conditions (O'Driscoll 1979). Some resources have been overused; for example, the peak flow in the Great Artesian Basin was reduced by 25% between 1918 and 1980.

Sedimentary river basins cover 60% of Australia. Natural recharge should allow an estimated exploitable yield of 72 000 GL a year (DNR/AWRC 1975).

Shallow aquifers

Human activities change the natural hydrological cycle; they have caused rising water tables over much of Australia. The introduction of agriculture (clearing deep-rooted perennials and replacing them with shallow-rooted annuals) initiates a period when the storage and distribution of subsurface salts move towards a new equilibrium (Peck et al. 1983). Irrigation accelerates the rate of change. The time taken for salt to reach equilibrium is usually much greater than for water because of the characteristics of soils and aquifers (Peck et al. 1983, O'Driscoll 1979).

In dryland areas the high water tables create lakes in localised depressions. The water salinity tends to be variable and to increase with time (Fig. 2). In irrigated areas rising water tables threaten crop production through waterlogging and salinisation (ABS 1997). Abdullah (1995) suggests that 24% of irrigated land in the world has lost productivity from these 2 threats, especially in arid and semi-arid regions.

Concentrating saline drainage water for use in aquaculture

Australia's low relief means a restricted number of good dam sites for the expansion of irrigation, and maintaining irrigation areas with high or rising water tables requires surface and subsurface drainage. To protect the root zone in these areas, shallow bores or tile drains are often used. This produces a saline effluent that must then be managed. Inland saline aquaculture is an example of how this 'waste' water can be used to generate income, as one of the later stages in a serial biological concentration system with improved internal drainage. The concept is based on the CSIRO 'Filter' system used to remove nutrients from secondary treated sewage.

Figure 1 shows how it works. Low-salinity water is applied to a salt-sensitive crop. The drainage, which has increased in salinity, is then applied to a moderately salt-tolerant crop. The drainage from this, with a still higher salinity, is applied to a highly salt-tolerant crop. The drainage from here is then used for aquaculture. (It is important to note that if there is no drainage, then salt rapidly builds up in the soil.)

Because the salinity of any surface water body increases by net evaporation loss in most of Australia, the aquaculture production pond must drain to another pond so that its salinity can be kept constant (Fig. 2). The final product is salt. The net result is the sustainable use of a potential threat to irrigated agriculture to generate further income

The philosophy behind the idea is based on not allowing drainage to flow to a sink until it is totally unusable for any productive purpose (Keller et al. 1996). Gooley et al. (these proceedings) describe a serial biological concentration system in operation in Victoria.

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Figure 1. A serial biological concentration system using modified soil plots to produce crops while increasing the salt concentration to that suitable for inland saline aquaculture. The final product is salt.

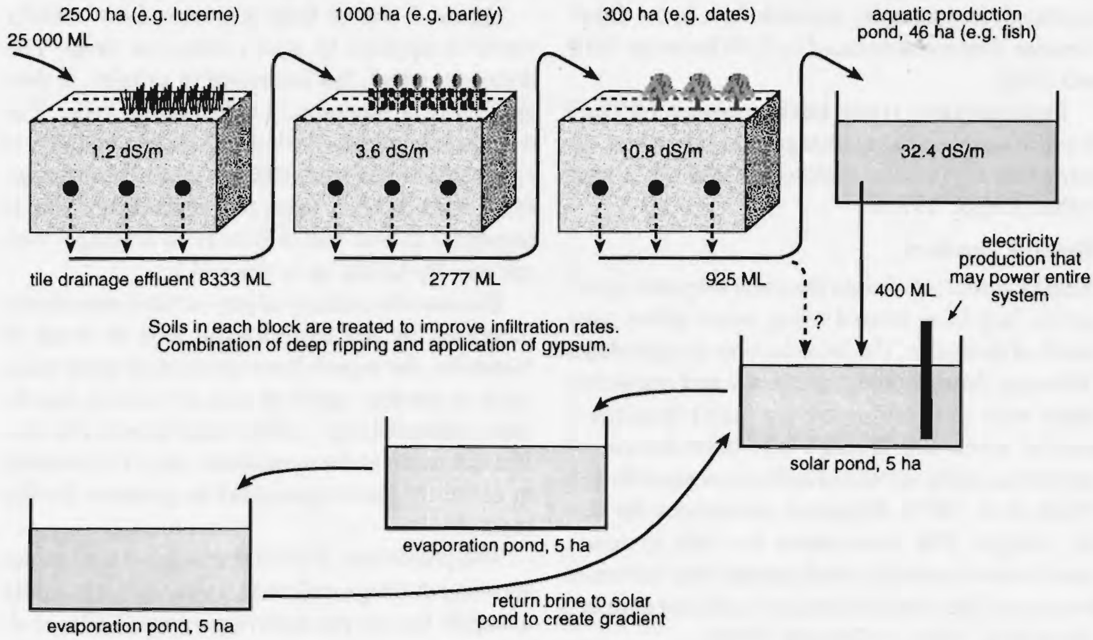
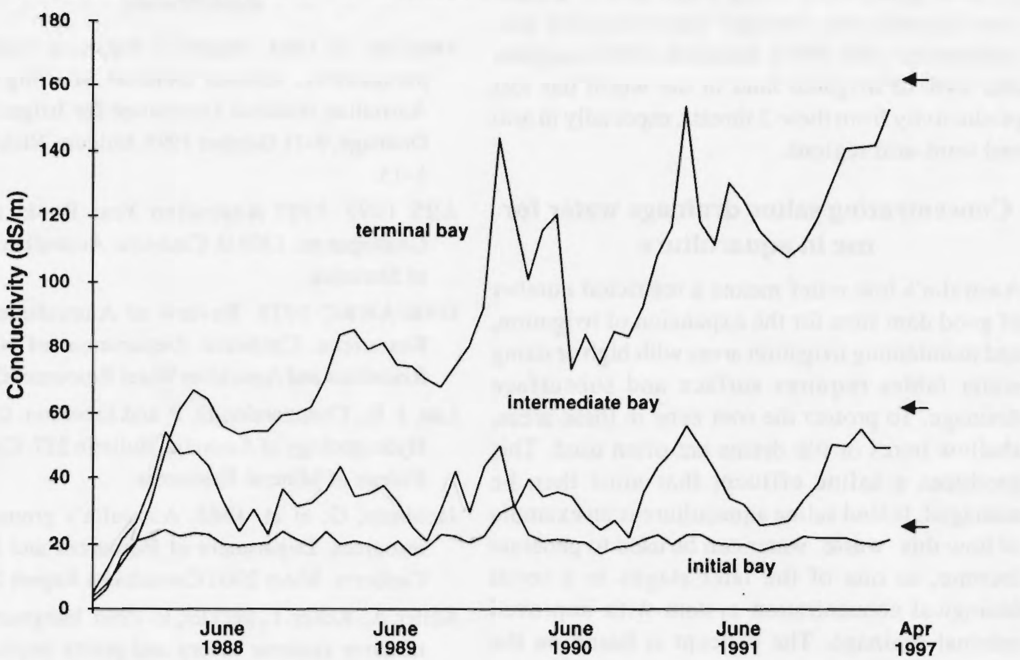


Figure 2. Salinity levels in 3 community evaporation ponds at Girgarre in the Shepparton area of Victoria (pers. comm. F. Leaney. CSIRO Land and Water, Adelaide, 22.7.97). The salinity in bays A and B is kept steady by continual transfer of water to Bay C, where the salinity continues to rise.



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A national environmental management policy for land-based fish farming

Jasper Trendall*, Jackie Alder† and Alan Lymbery‡

Changes in rural economies

The traditional base for agricultural economies in Australia is declining. The south coast of Western Australia, which covers an area of 5.4 million ha between Walpole and Esperance, is a good example of these changes. Farms in the region produce more than a quarter of Western Australian wool, and the value of agricultural production exceeds $500 million annually. However, the region has the state's lowest annual average income, and the populations in inland shires and towns are falling.

The economic base is declining at the same time as environmental changes are reducing the productivity of large areas of farmland. The environmental changes include salinity, erosion and eutrophication. In 1995 it was estimated that almost 10% of land in the south coast region was lost to salinity, and that up to 24% of the region could be potentially affected (Ferdhowsian et al. 1995). The loss in agricultural production is compounded by associated losses of water resources, wetlands, vegetation and public reserves. There is a direct relationship between these environmental changes and land and water management practices in agriculture. The future of agriculture on the south coast will also determine the future of the environment.

Sustainability means meeting economic, environmental and social needs

Between 1994 and 1996 the South Coast Regional Assessment Panel and the South Coast Regional Initiative Planning Team evaluated the specific requirements for sustainable agricultural production on the south coast of WA and the most appropriate way of managing changes. The result is detailed regional land and water management strategies (LWMSs) covering the entire south coast region. Two of the most important regional issues to emerge from extensive community consultation are increasing farm profitability, diversity and management skills, and keeping people in rural areas. It is now generally accepted that environmental and social needs underpin sustainable economies.

Recognition of the catchment as the basis for aquatic resource management

The environmental management of agriculture in Australia is now focused on river catchments. Catchment management groups range from large organisations, such as the Murray–Darling Basin Commission, to community-based groups that work in single catchments or areas within catchments. This is recognised in the LWMSs for the south coast. The single most important issue identified in the planning process was that salinity and related water management issues must be considered on a catchment basis. On the south coast there are now 20 land conservation district and catchment committees and 102 small catchment groups.

Farm diversification is based on new industries with new management needs

The future of primary production in areas such as the south coast of WA lies in new production systems, which allow farms to use water and land better and to diversify their economic base.

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Aquaculture has been identified as a potential new production system for farms on the south coast, but there is very little practical information that farmers can use to plan the integration of aquaculture production into a farm business. Equally importantly, established catchment management groups do not have the information necessary to incorporate aquaculture development into existing catchment management plans. The development of new industries, such as inland aquaculture in WA, creates an opportunity for government to define clear, practical management guidelines for sustainable production before, rather than after, the industry is established.

Aquaculture management of as a part of catchment management

Aquaculture production has a unique dependency on the water resources of a catchment. It can also directly affect those resources in a variety of ways. The necessary links between aquaculture and the aquatic environment make catchment management the most appropriate way of managing development. If aquaculture development is to be integrated into catchment management programs then we need more detailed information about the production systems. This information gives the basis for informed and equitable management guidelines. It should include analyses of the production economics, environmental impacts and social implications of aquaculture production.

The most effective basis for the development of a sustainable aquaculture industry would be environmental management guidelines that allow aquaculture to be incorporated into catchment management programs.

Process model, risk analysis and case studies

A general input–output process model for land-based production systems that would be developed using existing information on identified environmental risks and established production technologies would give a basis for detailing performance standards. The model would include contributions from aquaculture operators and management agencies and identify and take into account differences in production processes. The model could then be used to analyse the effects of aquaculture development on a catchment.

Environmental risk analysis using networks, event-tree analysis and life-cycle analysis can identify potential environmental impacts for the process model and selected case studies. These methods are commonly used to investigate risk associated with a development or activity and can help identify measures to mitigate some potential effects. Social effects can be considered through surveys, interviews, workshops and direct liaison with catchment management groups.

National environmental management guidelines for land-based aquaculture

A preliminary analysis of the cost to industry of implementing the operational requirements of the process model can be done by using existing economic data. Once the specific operational requirements, policies and estimated cost to industry have been determined, best practices, policies and guidelines can be recommended. The ability of the guidelines to meet best practice, such as ISO 14000 standards, can also be incorporated into the assessment by using the process model.

The results of the economic analyses, environmental risk analyses and data from case studies give the basis for defining a national environmental management policy that allows land-based aquaculture to be incorporated into catchment management programs. This will minimise potential environmental impacts, while maximising any competitive advantages that might exist for the industry.

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Ferdhowsian et al. 1995; Proceedings of the Fourth National Conference on the Productive Use and Rehabilitation of Saline Lands

Environmental considerations in the use and management of inland saline water bodies for aquaculture

Damian M. Ogburn*

Two fundamental objectives of aquaculture development are that it be environmentally sustainable and that it be economically viable. These issues are closely tied. It has been proved in numerous other human activities that if development is not sustainable then it is not viable. For any proposed aquaculture development, proponents must pay attention to planning principles, assess potential effects, and establish processes to minimise these effects through good aquaculture practices.

The use of saline water for inland aquaculture allows an opportunity to circumvent some of the conflict and environmental issues currently facing traditional coastal aquaculture. However, a number of significant issues need to be dealt with in considering aquaculture development proposals (Table 1). Five major areas of concern are discussed below.

Table 1. Environmental considerations for inland saline aquaculture developments.

Stage	Issues
Market selection	Demand, requirements, economics, proximity
Species selection	Closed cycle, exotic, diseases, performance
Site selection	Water source, climate, land
System design	Containment, control, failure risk, performance, predator risk
Management design	Training, good practices, health protocols, contingency plans, food safety
Waste stream	Containment, treatment, economics, failure risk
Alternative opportunities	Species or activity if venture fails, clean-up costs

Waste water disposal methods

Increasing salinisation of land and waterways in agricultural areas due to irrigation and deforestation is a global problem. Any aquaculture development using saline water must not increase salinisation and must minimise the release of nutrients to waterways. Consequently, the disposal of saline water from aquaculture systems needs to be carefully considered. There are two main methods of disposal:

- Closed-circuit systems, which concentrate the salt by evaporation. The products are various salt precipitates and bittern (the residual liquor from the precipitation process, consisting mainly of hygroscopic magnesium salts). The proposed quantity, quality and fate of these products also need to be considered.
- Reinjection of the saline water into the aquifer, usually into saline aquifers that are deeper than those from where the water is initially extracted. The water quality (such as introduced pollutants and pathogens) and the hydrological characteristics of the aquifer need to be considered.

Site contamination

The storage of saline water and salt at the aquaculture site could contaminate the surrounding water table, land and catchment. Containment and reticulation infrastructure and the risks associated with it therefore need to be considered.

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Issues include the water-holding capacity and physical characteristics of the soil in the case of earthen ponds, and secondary containment infrastructure in the case of pond failure and flooding.

Alienation of land

Soil contamination with salt might preclude alternative uses for the site if the venture fails. Proposals must consider how a site would be rehabilitated in that event.

Introductions of exotic species or associated pests or diseases

Aquaculture often depends on non-indigenous plants and animals. To evaluate proposed introductions requires a process for risk identification and assessment. The aim has to be risk minimisation and containment. Minimisation can be established through health protocols that the stock must achieve before translocation. Containment needs to apply not only to the species to be cultivated but also to potential vector paths for associated disease and pests that may not be identified in the protocols. Given the imprecise knowledge about and lack of diagnostic capabilities for certain potential pathogens, particularly viruses, clear containment and operational protocols to minimise potential contamination of the adjacent catchment need to be established before the development proceeds.

Management programs for animal interactions

Establishing an aquaculture operation may involve interactions with resident animals or attract new and unwanted ones. Management programs to deal with this must be clearly established at the outset; for instance, how to manage bird populations that could prey on the fish. Potential interactions between the aquaculture species and resident species need to be identified; for example, between cultured *Artemia* sp. and native anostracan species such as *Parartemia* sp.

Conclusion

Aquaculture has a strong tie with the environment through its prerequisite for good water quality. Not only can it provide considerable benefits to the community in terms of jobs and economic opportunities, but it can also act as a sentinel for some of the less observable effects of human activity that affect our water catchments. Aquaculture development that is planned with good-practice principles in mind must be sustainable if it is to be viable. The scope for integrating aquaculture activities into remedial solutions for salinisation of inland agricultural lands provides a new frontier for the modern systems approach to agriculture.

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Algae

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ALGAE ARE GROWN AS food, animal feed and sources of valuable fine chemicals. The microalgal industry is one of the largest commercial aquaculture industries in Australia. The main alga grown is the halophilic green alga *Dunaliella salina*, grown as a source of beta-carotene. It is produced by two companies, Western Biotechnology Pty Ltd in Western Australia and Betatene Pty Ltd in South Australia. These two producers are the largest in the world. The algae are grown in large (up to 150 ha), shallow (20–30 cm deep) ponds in water with salinities of 200–250 g/L NaCl (i.e. up to 10 × seawater). Proprietary methods are used to harvest and extract the beta-carotene. The beta-carotene is formulated into a range of products (e.g. 1.5%–30% in oil, water-dispersable beadlets, dried algal powder) and is exported to Japan, the USA and Europe as a health food supplement and a natural pigmenter for products such as margarine. Depending on formulation the beta-carotene sells for US$300–$600/kg.

Australia is very well suited to large-scale commercial algal culture, having a sunny warm climate, large land areas and generally unpolluted air and waters. Inland saline water sources, including ground water sources, are a valuable resource for this industry. The fact that these ground water sources are generally found in low-rainfall, sunny warm locations is an advantage, as algal culture requires a continuous reliable source of sunlight. Australia also has extensive expertise in commercial algal aquaculture and in the marketing of the algal products. Table 1 lists some of the algal species that can be grown and their salinity requirements. It does not list all possible species, but rather serves to give an overview of the wide variety of species and products. Many other species are being studied for their potential for commercial culture.

The technology for large-scale commercial algal culture varies depending on the species grown. *D. salina* is grown in very large, unstirred, shallow ponds, and *S. platensis* is grown in paddle-wheel-mixed raceway ponds. The other microalga species cannot be grown in open-culture systems as they are easily contaminated and overgrown by other species. These algae require closed photobioreactors such as the helical tubular system, the Biocoil™, developed by Biotechna Ltd and Murdoch University. These closed systems also have the advantage of giving much better control over the culture conditions than open ponds, so that a higher quality, more consistent product is produced. Their disadvantage is that they are more capital-intensive and thus require a more valuable product. The existing production costs for microalgae in fish and crustacean hatcheries around the world range from about US$60/kg dry weight to more than US$1000/kg dry weight (average US$400/kg). A dedicated, large-scale production facility would be able to produce the algae at significantly lower costs and would then ship them to the hatcheries. NSW Fisheries and Murdoch University are developing the technology for producing algal concentrates with a good shelf life and high nutritional quality, suitable for shipping.

Saline ground waters have a potential advantage over sea water for the culture of algae for food and feed; the quality of seawater often varies significantly through the year and can, at times,

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Table 1. Algal species that could be grown in saline ground water sources.

Alga	Product or market	Salinity (in g/L NaCl)	Status
Dunaliella salina	Beta-carotene	> 200	Commercial
Aphanothece halophytica	Polysaccharides, phycobilin pigments	> 200	R&D
Isochrysis, Tetraselmis, Chaetoceras, Pavlova	Feed used in the aquaculture of molluscs, crustaceans & fish	about 30	Presently produced in various hatcheries
Spirulina platensis	Health food	up to 30	Commercial (in USA, Thailand, China, India)
Porphyridium cruentum	Polysaccharides, pigments for cosmetics	up to 30	R&D
Gracilaria spp.	Feed used in aquaculture of abalone; source of agar	about 30	Mainly wild harvest, but also some culture overseas
Ulva spp.	Feed used in aquaculture of abalone	about 30	Some small-scale production overseas
Caulerpa spp.	Luxury food (sold mainly in Japan)	about 30	Presently farmed in the Philippines

be unsuitable for algal culture. A reliable, clean source of saline water can improve the commercial viability of an algal culture facility.

The macroalgae *Ulva* and *Gracilaria* are grown free-floating in stirred tanks, whereas *Caulerpa* is grown on the bottom of shallow (50–100 cm deep) ponds. Onshore cultivation of marine seaweeds is becoming more and more popular because of the limited availability of nearshore sites suitable for algal farming and because of the high cost of building and maintaining structures for these farms in the sea. Although all existing farms are near the sea, there is no reason why farms could not be located inland near a suitable saline ground water source.

Another possible system using saline ground water is an integrated algal – brine shrimp farm. The brine shrimp *Artemia* is in high demand as a feed source for fish culture, especially for ornamental fish, and demand is significantly greater than available supply. One of the preferred food sources for *Artemia* is *Dunaliella salina.* The combination of a *Dunaliella* plant with an *Artemia* production facility could be an attractive commercial proposition. One advantage of this would be that the overall facility could be smaller than a *Dunaliella* plant for beta-carotene production, which requires economics of scale to offset the high capital investment required for the harvesting and extraction equipment.

Potential of inland saline water for aquaculture of molluscs

C. L. Lee*

THERE IS LITTLE information on the aquaculture of molluscs in inland saline waters nationally and internationally.

In Australia, at least two groups of molluscs (Gastropoda: genus *Coxiella* and Bivalve: genus *Corbiculina*) are known to be endemic to inland saline lakes (McMichael 1967). Both groups are small molluscs with no aquaculture potential, but many species that are non-endemic to inland saline water may have potential for culture in these waters. Table 1 lists species with potential.

Table 1. Mollusc species with potential for aquaculture in inland saline waters.

Edible oysters	
Pacific oyster	*Crassostrea gigas*
Sydney rock oyster	*Saccostrea commercialis*
Tropical oysters	*S. amasa* and *S. echinata*
Flat oyster	*Ostrea angasi*
Pearl oysters	
Silver-lipped oyster	*Pinctada maxima*
Black-lipped oyster	*P. margaritifera*
Winged oyster	*Pteria penguin*
Abalone	
Blacklip abalone	*Haliotis rubra*
Greenlip abalone	*H. laevigata*
Roes	*H. roei*
Tropical abalone	*H. asinina*
Other molluscs	
Blue mussel	*Mytilus edulis*
Scallops	*Pecten fumatus* and *Amusium* spp.
Trochus	*Trochus niloticus*
Giant clams	*Tridacna* spp. and *Hippopus* spp.

Among the species listed, only three have been investigated for their potential for culture in inland saline water in recent years: the Pacific oyster, the Sydney rock oyster and the trochus.

Ingram et al. (1996) reported that a preliminary trial on the culture of the Pacific and Sydney rock oysters in inland saline water from the Goulburn irrigation area of Victoria showed poor growth rates, and attributed the result to the poor nutrients found in the water. In contrast, Peter Rankin (pers. comm.) reported good growth rates for Pacific oysters cultured in coastal salt ponds in Victoria using seawater.

In the Northern Territory, the Northern Territory University (NTU) trochus hatchery obtains its water from a saline bore sunk to a depth of 56 m. The bore water has a salinity of 51–52 g/L, and the salinity has been constant throughout the last five years of operation. The water has been successfully used in spawning trochus; during the last four years, millions of postlarval trochus have been produced in the hatchery. The hatchery has also closed the life cycle of trochus after 2.5 years, and the hatchery is currently carrying mature F_2 trochus. This is the first reported case of closing the life cycle of a marine mollusc using saline bore water. A full description of the design and operation of the NTU's hatchery is given by Lee (1997).

In 1997 the NTU hatchery began a trial on holding and spawning the giant clam *Hippopus hippopus*. Future work will include the spawning and juvenile production of the tropical abalone and study of the growth rate of the black tiger prawn, *Penaeus mondon,* maintained at different salinities.

Table 2 shows an analysis of the NTU's bore water. After the water is treated and diluted to 35 g/L salinity, its composition is similar to that of seawater. In WA, the Tropical Aquaculture Park

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Table 2. Quality of saline water for mariculture in NTU, Victoria (Goulburn irrigation area) and Western Australia (Tropical Aquaculture Park, Broome).

	Ionic concentration (mg/L)				
	NTU raw bore water	NTU treated bore water[a]	Victoria[b]	WA[c]	Sea water
Na	16 400	10 700	9 450	9 536	10 500
Mg	2 059	1 349	1 645	1 150	1 350
Ca	689	447	1 225	357	400
K	514	339	87.5	357	380
Fe	20	0.30	–	–	0.02
Si	20	15	–	–	8.6
Cl	30 250	20 000	14 455	19 392	19 000
F	0.0	–	0.4	–	1.3
SO_4	4 800	2 850	4 480	2 393	2 560
Salinity (g/L)	51	35	35	35	35
Turbidity (NTU)	–	2	–	18	–
pH	6.2	7.9	–	7.4[d]	8.2

a: 24 h aeration, 72 h sedimentation and dilution to 35 g/L

b: Data provided by Brett Ingram, Marine and Freshwater Resources Institute, Victoria

c: Data provided by WA Fisheries. Salinity (g/L) calculated as $1.806 \times [Cl^-]$ (g/L) and adjusted to 35 g/L

d: pH at 49 g/L salinity. Could be different after aeration and dilution to 35 g/L

in Broome has a saline bore water supply (35 m deep; 49 g/L salinity). The chemical composition of the water is similar to that of the NTU water. The water is therefore suitable for aquaculture but its potential is yet to be tested. In contrast, the composition of the saline water from the Goulburn irrigation area of Victoria is different from that of seawater. For example, its magnesium, calcium and sulphate concentrations are much higher than those occurring in seawater and its potassium and chloride concentrations are lower. The differences in the ionic composition of inland saline waters of different origins are likely to have large effects on the growth and survival of euryhaline mollusc species and hence determine their suitability and potential for inland saline aquaculture.

Based on current information, it appears that inland saline water has potential for monoculture of non-filter-feeding and benthic grazing molluscs such as abalone, clams and trochus, and for culturing molluscs in polyculture with finfish or crustaceans.

NTU's results indicated that the potential for using saline water from deep aquifers for hatchery production is excellent. Bore water of marine origin could have many advantages over raw seawater for hatchery work, including the following:

- Consistently high water quality.
- Free of organic matter contamination.
- Free of bacteria and other infectious agents.
- Does not require UV, chlorination or other treatments.
- Natural filtration, resulting in negligible TDS and water turbidity.
- Requires minimal treatment for microalgal

culture.

- Could be retained in reticulation pipe for extended period without odour or other problems.
- Gives a high level of quarantine to the hatchery.
- Hatchery system is cheaper and easier to set up, maintain and run.

Saline water has potential for grow-out production of various mollusc species. However, its suitability is likely to depend on the composition and nature of the saline water and the species to be farmed. Saline bore water from deep aquifers has great potential as a water source for hatchery production of aquaculture species. Its potential is yet to be fully investigated and developed.

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Potential for inland saline aquaculture of crustaceans

Geoff L. Allan* and D. Stewart Fielder*

In Australia, crustacean aquaculture is dominated by penaeid prawns, mainly the giant tiger prawn (*Penaeus monodon*) and the Kuruma prawn (*P. japonicus*). A number of other species have been cultured in small quantities, including school prawn (*Metapenaeus macleayi*), greasyback prawn (*M. bennetae*), banana prawn (*P. merguiensis*), brown tiger prawn (*P. esculentus*), eastern king prawn (*P. plebejus*) and the western king prawn (*P. latisulcatus*). Freshwater crayfish, including red claw (*Cherax quadricarinatus*), yabby (*C. destructor*) and marron (*C. tenuimanus*) and small quantities of mud crabs (*Scylla serrata*) are also farmed. Total production of crustaceans increased from 1.1 kt in 1990–91 to 1.9 kt in 1995–96.

Attempts have also been made to culture freshwater prawns (*Macrobrachium rosenbergii*), brine shrimp (*Artemia* spp.) and sand crabs (*Portunus pelagicus*). More recently, the culture potential of Balmain bugs (*Ibacus peronii*) and marine crayfish has been discussed. In NSW, *P. monodon, P. japonicus* and *C. destructor* are the most commonly farmed crustaceans.

Although intensive culture of at least some crustacean species in tanks and raceways has been investigated, commercial production is almost entirely based on culture in earthen ponds.

To evaluate the potential of inland saline water culture of crustaceans, information is needed on the quantity and quality of the water, the composition of sediment, the cost of constructing ponds, and the cost of supplying infrastructure such as electricity, transport and staff. Apart from the water, the other aspects influencing culture potential are similar in both inland saline areas and areas traditionally used for culture operations and will not be covered further here.

The quantity of water available in different locations will need to be assessed. Although saline groundwater is plentiful in many areas, obtaining the appropriate salinity may require mixing waters from different sources, which could prove a limitation. If evaporation ponds where salt is to be harvested are to be used for aquaculture, the potential for waste water containing organic matter and nutrients to contaminate the salt needs to be assessed.

Water quality encompasses physical factors such as temperature, salinity, dissolved oxygen and other gases, ionic composition, pH, nutrients (such as ammonia, nitrite, nitrate and phosphorus) and any contaminants such as pesticides or hydrocarbons. It also includes biological factors such as bacterial composition and content (e.g. *E. coli* counts) and the presence and concentration of algae and yeasts. All of these variables need to be considered when looking at aquaculture of any species anywhere. For inland saline water, ionic composition and salinity will have a large bearing on its suitability for culture of crustaceans (Table 1).

Probably the best candidate for inland saline water culture is penaeid prawns, although *P. monodon* performed poorly in preliminary trials conducted in Victoria (pers. comm. Brett Ingram).

Ruello (1996) reports that *P. vannamei* has been successfully cultured in saline groundwater in southern Texas, and that three penaeids (*P. kerathus, Metapenaeus monoceros* and *M. stebbing*) were growing faster in an inland saline lake in Egypt than in the Mediterranean.

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Table 1. Salinity tolerance and optimum conditions for crustaceans.

Species or group	Salinity tolerance or optimal concentration
Freshwater crayfish	
Cherax destructor	6–8 g/L upper level for growth, 22 g/L upper lethal level (8 d)
C. tenuimanus	20 g/L upper lethal level (85 d)
C. quadricarinatus	Can reproduce in water up to 18 g/L. Can tolerate > 12 g/L for extended periods
All three species	Optimum likely to be 0–5 g/L
Freshwater prawns	
Macrobrachium rosenbergii	Requires 12–15 g/L to reproduce. May be grown in ponds at about 10 g/L
M. australiense	Does well in freshwater only
Penaeids	
Penaeus monodon	Isosmotic value 23–25 g/L. Optimum for culture 15–25 g/L. Cultured successfully at < 5 g/L in Thailand
P. japonicus	Isosmotic value close to 35 g/L. Lower lethal level 19.3 g/L at 10°C, 12.1 g/L at 14°C, 5.4 g/L at 25°C. Optimum 27–31 g/L
Metapenaeus macleayi	Isosmotic value 27 g/L. Has been successfully farmed at 5–35 g/L
Other species	
Marine crayfish and bugs	Stenohaline—require oceanic-strength seawater
Mud crab (*Scylla serrata*)	Best at 28–34 g/L. Can tolerate fresh water for extended periods (days)
Sand crabs (*Portunus pelagicus*)	Prefers higher salinity and can tolerate hypersaline conditions
Brine shrimp (*Artemia* spp. and *Parartemia* spp.)	Endemic in inland saline lakes. Tolerates hypersaline water

Artemia spp. were introduced into Australia in the 1970s. They grow well in Western Australian saline lakes and have considerable commercial potential as an encysted live food for the aquarium trade and fish hatcheries. Endemic *Parartemia* spp. may also have potential. The quality of the nauplii from Australian *Artemia* is apparently quite high. *Artemia* spp. also have a market as frozen adults for the aquarium trade. This product has a high value, and a market opportunity remains unfilled.

Because of their very high growth and reproductive potential, *Artemia* may also have potential for production as a protein source for humans or livestock, although the cost of production and processing will obviously be critical considerations.

Freshwater prawns may be a suitable candidate in more tropical regions in Queensland, the Northern Territory and WA. Freshwater crayfish are likely to be suitable candidates only in low-salinity waters (≤ 5 g/L). Marine crayfish and bugs are likely to be too stenohaline to tolerate the fluctuations in salinity likely to occur in facilities using inland saline waters, and as culture technology for these species has not been developed they have low priority for investigation.

Potential for inland saline aquaculture of fishes

Greg Jenkins*

SIGNIFICANT INTEREST exists in the use of inland saline waters in Australia for aquaculture. This interest has been generated as a result of the lack of suitable coastal sites, the availability of saline water through salinity control programs, and the presence of saline reserves in deep aquifers.

The prospect for commercial culture of fish in these waters appears, on face value, to be good. Numerous examples exist throughout the world where ground water is used for the culture of fish. This water is usually extracted from deep aquifers.

There are two methods by which the potential of a saline water source can be assessed for fish production:

- Correlation of the water characteristics with parameters conducive to the survival of brackish or marine fish. The parameters include salinity, ionic composition, temperature, pH, volume and presence of contaminants. This assessment would need to take into account technologies available to improve undesirable parameters such as low dissolved oxygen levels, excessive metals or the presence of sulfides.
- Field trials (or trials with water samples collected from the field) to test species tolerance to and performance in each potential water source. At the Fremantle Maritime Centre in Western Australia the initial test for a water sample's suitability for black bream or snapper survival has been a 'bucket' bioassay.

The tolerance of various fish species to waters with varying ionic compositions is largely unknown. Consequently, field and laboratory trials will be vital in the early stages of assessing the potential of inland saline waters for aquaculture until a database of the ionic tolerance of a range of species has been established.

Once the water is found to be suitable for commercial fish culture, the next step is to determine the production methods and to judge the likely costs, benefits and possible cost offset for the venture.

Saline water sources

Saline lakes

These are usually extensive and vary constantly in salinity and volume. Most dry up in summer. Species cultured will need to be euryhaline.

Potential: Low overall potential for Australia, although commercial culture may be possible in some lakes. There may be potential for intensive production in cages or for extensive put-and-take production in some of the larger lakes.

Salinity control programs

Saline water pumped from shallow aquifers for land protection or reclamation is usually directed to evaporation basins, although many farmers still drain it onto adjacent land. The salinity of the water produced varies over time, and the sustainable volume is directly related to the aquifer recharge rate. The salinity and volume of water are site-specific and may vary considerably within a very short distance.

Fish would be raised in the evaporation basins. Euryhaline species will be required. The investment should be small until the salinity and sustainable volume are established.

Production methods could include floating cages within the evaporation basin, extensive pond

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production, intensive production in purpose-built and drainable ponds, and intensive tank systems. The latter two methods would be hard to justify for commercial culture until results from on-farm research trials are available.

There are four major limiting factors for fish culture in evaporation basins:

- Ambient temperatures. Temperature fluctuations in temperate regions may restrict the number of species that will grow to a saleable size in an acceptable period of time.
- Low flow rates. These are common for all but very large evaporation basins.
- Difficulty of waste removal. The key cost offset for an evaporation basin is the production of salt. Wastes generated by commercial fish culture within an evaporation basin would be detrimental to the production of high-quality salt.
- Required depth of water for fish culture. This will place additional pressure heads on water tables and may require a higher-quality pond lining than would otherwise be necessary.

Integrating commercial fish production with land protection or reclamation works is attractive from an economic point of view, as much of the capital costs associated with earthworks may be justified by the potential benefits associated with increased agricultural production.

Potential: Low to moderate. Many developments will probably be small-scale activities such as extensive production for local markets or put-and-take tourist ventures to help with farm diversification. Opportunities for larger-scale activities may be less common, and development will depend on economic considerations.

Deep saline water reserves

These are likely to offer the best options for inland saline fish production. If the water quality is suitable for marine or brackish fish then the major limitations will be the costs of capital, production and marketing.

Water from deep aquifers has several advantages:

- It is more dependable and uniform in quality and quantity than surface water.
- It is free of wild fish eggs.
- It is free of predators and parasites.
- It is less polluted than surface water.
- It has a more constant temperature than surface water.

Deep artesian water is also frequently warm. This allows the production of tropical fish in temperate areas or the culture of fish at optimum temperatures for growth by cooling of the water to the desired temperature.

Saline aquaculture operations using deep saline waters are unlikely to be integrated with saline land control measures or to be able to offset infrastructure and operating costs against salinity control programs. They will require intensive production methods for good economic returns, and the risk is correspondingly increased.

Potential: Medium to high. Depends highly on water quality, species and economics.

Endemic fish species

Short-term candidates

There are several fish species with reasonably well known culture technologies and for which juveniles are available for inland saline aquaculture projects in the short term. All are euryhaline to varying degrees—an important consideration for inland saline aquaculture.

Australian bass (*Macquaria novemaculeata*)

This eastern Australian species is highly prized by sports fishers for its fighting qualities. Culture methods have been developed in NSW. The species is reared in greenwater ponds for stocking as juveniles for recreational fishing opportunities.

The commercial culture of this fish in inland saline waters would be primarily for put-and-take.

Barramundi (*Lates calcarifer*)

The barramundi is recognised as an excellent sports fish and a premium table fish. Barramundi has been commercially cultured in Australia since the mid 1980s. The culture methodology and cost of production are well known, and a domestic market exists for the product.

A commercial barramundi farm in inland NSW is sourcing saline water at approximately 20 g/L salinity from a deep aquifer. The barramundi are grown in an intensive tank system, and the waste water is directed back to the aquifer.

Black bream (*Acanthopagrus butcheri*)

The availability of black bream juveniles has generated an enormous amount of interest in the aquaculture potential of the species. Black bream are now growing in farm dams from Carnarvon to Esperance in WA. Fingerlings have also been sent to fisheries researchers and farmers in South Australia, Victoria and Queensland for aquaculture trials.

Black bream is well adapted to freshwater environments and has been observed in hyper-saline lakes with salinities up to 140 g/L with no physical signs of stress (pers. com. Gavin Sarre, Murdoch University Fish Research Group, Perth, WA, July 1997). A study supported by the Fisheries Research and Development Corporation has begun in WA to determine the survival and growth rates of black bream at a range of salinities and temperatures.

The remarkable euryhaline nature of the black bream makes it suitable for consideration for inland saline aquaculture. However, the economics of production and marketing is unknown.

Eel (*Anguilla australis*)

Although most eel culture in Australia is extensive, using elvers captured in Tasmania, there may be possibilities of culturing them in intensive systems in inland saline waters. However, the level of skill involved in intensive eel culture, the absence of breeding technology and the 'Houdini' reputation of eels are deterrents for potential investors and government regulators.

Mulloway (*Argyrosomus hololepidotus*)

Mulloway is a fast-growing euryhaline species. It will tolerate a wide range of salinities and is a recognised sports fish. It is accepted as a table fish in some states. NSW Fisheries has developed the culture methodology for the species and is currently refining the techniques to reduce costs for a mulloway stock enhancement program.

Put-and-take tourist ventures would be popular in WA, where inland fishing opportunities are limited; commercial ventures to produce the mulloway as a food fish may be justified in the eastern states of Australia.

Greenback flounder (*Rhombosolea tapirina*)

The ability of the flounder to be cultured intensively and exported alive relatively easily makes it a potential candidate for inland saline aquaculture.

Pink snapper (*Pagrus auratus*)

Researchers and industry in NSW, Victoria, SA and WA have shown interest in growing the pink snapper in inland saline water.

The Cooperative Research Centre for Aquaculture supported NSW Fisheries in a project to investigate the potential of pink snapper for inland saline aquaculture, and the Marine and Freshwater Resources Institute (MAFRI) at Snobs Creek in Victoria has tested snapper in cages in an evaporation pond.

Experiments in WA have established that pink snapper juveniles will survive in salinities as low as 8 mg/L. Growth trials are planned at a range of salinities. Five hundred juvenile snapper are growing in a cage in a salt lake at Watheroo, 300 km north of Perth. The salinity of the lake is 29 mg/L. The snapper survived a record-breaking cold spell during July 1997 when the lake temperature reached 8°C.

Rainbow trout (*Oncorhynchus mykiss*) and Atlantic salmon (*Salmo salar*)

Research by MAFRI in saline evaporation ponds at Undera, Victoria, has shown that both species have potential for culture in inland saline water (pers. comm. Geoff Gooley, MAFRI, July 1997). Trials have indicated that acceptable growth rates can be achieved during winter. Additional commercial trials are planned in the near future.

Silver perch (*Bidyanus bidyanus*)

The salinity tolerance of silver perch and the promising results achieved by MAFRI in Victoria makes it good species for further investigation.

Sand whiting (*Sillago ciliata*) and Trumpeter whiting (*Sillago malucata malucata*)

The preference of whiting for silty or muddy bottoms may make them suitable for extensive culture in evaporation basins.

Mullet (*Mugil cephalus*)

Although mullet are not cultured in Australia and juveniles are not available from hatcheries, the species may have potential for culture in inland saline water. Mullet will tolerate extremes of salinity and temperature, and a lucrative market exists for mullet roe.

Longer-term candidates

Fish with potential for inland aquaculture in the longer term (as reliable culture methods are developed) include mangrove jack (*Lutjanus argentimaculatus*), estuary cod (*Epinephelus coioides*), King George whiting (*Sillaginoides punctatus*) and various other marine and estuarine species.

Non-endemic fish species

The use of inland saline waters creates possibilities for the introduction of non-endemic species from outside Australia for aquaculture. The aquaculture industry could have tighter controls over such species than the aquarium trade presently has over species allowed to be introduced under current quarantine regulations.

A strong case for translocation could be established where the area of culture is in an internally drained catchment and the species could be shown to be produced economically for the benefit of the nation. Such species would be required to have known culture technologies, excellent market prospects, and either a very high market price (for export) or a very low cost of production (for import replacement).

Aquarium (or ornamental) fish culture in Australia is increasing and will present excellent business prospects if live aquarium fish imports are banned in the future. Although most imported species are cultured in fresh water, several popular species will tolerate increased salinity (e.g. mollies, white-clouds and various cichlids). Several species of native Australian fish will also tolerate salinity, such as blue-eyes (*Pseudomugil* spp.), hardieheads (*Craterocephalus* spp.) and the desert goby (*Chlamydogobius* spp.).

Growout opportunities and markets

One problem that aquaculture developments have faced in Australia is in positioning product in the competitive domestic or international marketplace. Much of this problem has been due to the relatively high cost of production of fish in Australia. Opportunities to offset costs of production against saline control programs will make the product more competitive. However, the aquaculture venture must still make money. The biggest costs of a project are capital, feed and labour; the proportional cost of water is generally small.

Three points need to be considered when planning a project:

- Ensure that capital costs can be justified economically, or use existing facilities such as evaporation ponds.
- Increasing labour costs may be associated with increasing intensity.
- Optimum conditions for fish growth are required, or feed costs will be higher because of longer growout times or a higher feed conversion ratio.

It is well recognised that the international market for fish is expanding, but local opportunities should not be ignored. Small-scale farm-diversification aquaculture projects are more likely to target local and state markets than export markets. The potential for tapping into the ever-expanding recreational fishing market may also be a bonus for aquaculture projects associated with saline control measures in which fish are grown extensively in ponds for put-and-take fishing.

Advantages of put-and-take and ecotourism ventures when associated with inland saline control measures could include use of existing ponds, lower feed costs, higher return on product, greater range of species, and additional social benefits such as farm-stays.

Recommended actions

- Develop a data base of characteristics of inland saline water sources.
- Test survival and growth of a range of fish species on-farm. The initial screening of water suitability for fish survival may be a 'bucket' bioassay.

- Do not exclude species that have performed poorly in trials at one site as possible candidates at other sites.The ionic composition of water at each site will vary, and species suitable for culture may vary.
- Explore the option of recreational activities in association with evaporation ponds.

Summation of outcomes of day 1

Ned Pankhurst

We have three resources—natural saline lakes, shallow aquifers and deep aquifers—and two main problems—management of saline groundwater and constraints on coastal aquaculture sites. Putting them together gives us some options.

Natural saline lakes

These tend to be ephemeral and to have their own natural ecosystems. They are generally not relevant in terms of groundwater management. Aquaculture options are not attractive because of the inconstancy of the resource, and there are potentially the same resource consent problems as at coastal sites.

Shallow aquifers

Advantages

- Numerous sites.
- Engineering infrastructure is often in place.
- Any extra use offsets management costs.

Disadvantages

- Highly variable composition, temperature and salinity.
- May be contaminated.
- Flow rates may not support aquaculture operations of any size.
- Where groundwater management is successful, water supply may not be sustainable, or the character of the water may change with time.
- End use (salt production) may not be compatible with aquaculture.

Deep aquifers

Advantages

- Consistency of water quality.
- Water often of high quality for aquaculture.

Disadvantages

- Groundwater management programs cannot support the infrastructure cost.
- Deep extraction does not contribute to groundwater management; it could even exacerbate problems.

Conflicting requirements

There is a potential conflict between the requirements of groundwater management and aquaculture. Water from a shallow aquifer is the least desirable for aquaculture but the most desirable for land management, whereas water from a deep aquifer is the most desirable for aquaculture but potentially detrimental for land management. This conflict suggests that the subset of conditions where both land management and aquaculture requirements can be met is considerably smaller than the size of total resource. However, does this matter given the potential income from a relatively small resource volume?

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Economic considerations in setting research priorities for inland saline aquaculture

Perry Smith*

It is very difficult to identify any aspects of research management that do not have at least some economic element involved. Setting research priorities to consider an area of potential development includes identifying the opportunities and constraints, defining potential research programs needed to realise those opportunities, and setting the research budget. Economic issues are involved in identifying and pursuing the most effective means of doing the core research. Later in the research process come opportunities for reviewing the priorities within a program, the program itself and the commercialisation processes, and maximising the value of those results. All have a major economic component.

Defining opportunities and constraints

In setting research priorities we are attempting to define the opportunities and constraints facing individual industries and to rank them in terms of their respective payoffs. This allows us to define the most efficient means of working on specific problems or to establish the most efficient use of research and development resources.

Defining opportunities

In assessing the potential for productive investment in any aquaculture development there are a range of perspectives to be considered, including production systems, market potential and resource use (What is the best use of an available resource?). But the key criterion for assessing potential is whether the target species can be profitably produced, given these factors. Only profitability brings these elements together.

Consideration of production systems brings together a range of factors, including biological characteristics (reproduction, growth rates and density considerations, food conversion rates, and site requirements). Different technologies may have quite different effects on these factors.

The market potential factors include the availability of existing markets for the output, their seasonality and their ability to absorb higher volumes at different price levels, the form of the product, market-specific requirements and the level of cost involved to meet those requirements (including handling, transport and processing costs), and the existence of barriers to marketing (such as tariff or non-tariff impediments).

Resource use considerations include alternative uses of the resource and the potential trade-offs between development and preservation options.

Defining constraints

Appropriate skills, technologies, feeds, economies of size, infrastructure, government policies and the availability of finance are all key elements in establishing any industry. All need to be incorporated into the priority-setting process at an early stage; their absence is likely to act as a constraint to the adoption of research. For example, the absence of financial information on the likelihood of commercial viability will act as a major constraint to private-sector interest.

A key background issue in relation to establishing product opportunities in saline aquaculture is the relationships with government policy frameworks. Land tenure, land use and water use issues are all areas where policy will have a great effect on the opportunities and approaches that may be most productive. For example, salinity is a major national issue, and the economic frameworks being developed to resolve salinity

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problems will have a large bearing on the feasibility of inland saline aquaculture. In its general form the policy framework is increasingly based on economic resource use principles to ensure that resources are applied to their most valued use. If activities result in significant external costs or benefits then mechanisms should exist to ensure that these are reflected in the activities that generated them. Conversely, the benefits of activities that lessen the negative effects of other sectors' activities should also be reflected in the charging structure.

Water use policies, including charges for water use and discharge, may be an important element in relation to development opportunities for inland saline aquaculture. An efficient water use policy ensures that resources are applied to their most valued use. Charging policies for water use increasingly reflect the costs of providing that water, including the forgone opportunity of using the water in other ways. If such charges also reflect the differences in water quality before and after use, activities that increase salinity would be charged for the quality deterioration, and activities that decrease that salinity would be credited. Their existence may well provide a range of opportunities for saline aquaculture activities that may help in ameliorating the physical damage associated with increased salinisation or its economic effects. Similar interactions may occur with land use policies being developed to reduce the problems caused by various practices.

The availability of specific and general infrastructure can also have a major effect on the viability of inland saline aquaculture. Any industry that improves the use of existing infrastructure will obviously have advantages over one where the existing infrastructure does not meet the needs of the project. Moreover, the existence of more general social infrastructure will have indirect influences on aspects such as the availability and willingness of skilled staff to work on remote projects.

Setting priorities

There are several ways to compare and rank the identified opportunities. These range from a subjective assessment based on the best available advice on biological and technical production systems, farm economics and marketing, through to rigorous benefit–cost analysis (which encompasses a range of techniques). Even when using benefit–cost approaches, subjective assessment is needed to reduce the available options to a feasible set for further examination.

Some form of benefit–cost framework is needed to assess the attractiveness of different research options, so that we may define the likely rankings of projects and the total investment that should be made in an area based on the likely return to the marginal project. However, it is generally infeasible to pursue the benefit–cost option completely because of the lack of information, time and resources; a more general framework is needed. The Fisheries Research and Development Corporation combines subjective assessments of both the feasibility of research and its relative attractiveness based on benefit–cost principles to rank projects within an area.

A benefit–cost framework is valuable as a systematic means of guiding research decisions. Identification of the effects of varying the parameters on the economic outcomes gives vital information, including the economies of size necessary to achieve best outcomes and the identification of the costs associated with different constraints. For example, the feasibility of a project based on exporting its output needs to be assessed in relation to a range of exchange rates. The question implicitly asked is whether the project is likely to be feasible over the range of exchange rates likely to prevail over the life of the project.

Benefit–cost techniques are based on identifying the additional profitability to the industry resulting from the research (the total revenue from the activity less the costs involved—including the opportunity costs of both capital and labour—less the revenue they would return in their next best application) and changes in consumer surplus (the difference between what consumers are prepared to pay and what they actually pay) to take account of the benefits to consumers of the increased production. Both the income and cost flows are amortised to provide a single value of the project that can be compared with other like projects.

The main challenge in relation to benefit–cost techniques is to be able to assess the revenue and cost streams realistically. For comparisons to be made across projects, consistency in application is an important issue. A common basis for analysis allows research priorities to be established and also allows for development of strategic approaches to research and project implementation.

Opportunity costs, yields and returns

Identification of the opportunity costs of the resources involved is an important aspect of assessing inland saline aquaculture activities. Incorporating opportunity costs (identifying the next best use of those resources) provides a weighting to the benefits of development in an area where there are few other options over a project that uses a range of resources with a large number of alternative uses. The development of saline aquaculture in highly popular areas involves greater opportunity costs than in inland areas. Similarly, the advantages of using saline water should be reflected in the low opportunity costs of that water in other uses.

Estimation of revenue flows also presents a major problem, not only in terms of identification of the likely yields involved but also in terms of estimation of farm gate prices. Yields, mortality and feed conversion are all operator-dependent, and operator skills have had a large effect on the commercial viability of aquaculture operations in Australia. Very often there are few guidelines in relation to expected yields. The only assessments have been based on the experience of overseas operators in different conditions using different species (for example, snapper farming). For these reasons, sensitivity analysis is an important element of any project assessment.

Market returns represent a similar challenge. It is difficult to identify a benchmark price for a range of species, either because of the absence of comparable species in regular trade or because the likely effect of the additional supplies on prices received is understated. For larger projects the costs of marketing are also invariably understated. Nonetheless, an evaluation of market feasibility is extremely useful because it also defines many aspects of the target market that farming may have a comparative advantage in supplying, such as fish of a particular size or supplies at a particular time of the year where alternative supplies are low.

Key environmental constraints for research

Session coordinator: Alan Butler*

THIS WORKSHOP plenary session identified three categories of saline water resources: shallow aquifers, saline lakes and deep aquifers. We attempted to treat these separately by identifying key researchable environmental constraints, spending most time on shallow aquifers. Major researchable issues (without specific detail) are identified in bold type below.

With regard to shallow aquifers, members noted the spatial and temporal variability of the supply, quality and temperature of the water. Research on ways to control this was mentioned. Inland aquaculture operations are likely to consist of a large number of small operations with different parameters. Among other things this has implications for species selection and economics. The discussion led to the proposal that there needs to be **a water and land resource inventory**. Much of the material for this is already held by the States. This would allow sites to be identified and suitable fish to be chosen. It might also identify opportunities to use water in large land management schemes.

An alternative suggestion was to identify fish with aquaculture potential and then to look for sites. This drew attention to the question, already raised earlier in the meeting, of whether we are talking primarily about aquaculture as such or seeking to integrate it with, and thus to ameliorate, problems (salinity, rural economics) that have to be solved in any case.

Integration with serial biological concentration systems was discussed as a major research opportunity. The major issue here is that water goes into the culture system and emerges with a changed composition (nutrients, temperature, salt content etc.). We have to ask how this changed water will interact with the rest of the serial biological concentration (SBC) system; in particular, whether it will affect the production of high-purity salt. **Development of systems for scrubbing** nutrients and particles from water (perhaps themselves culture systems) is therefore a research issue.

If effluent does not go on to further stages in a managed, closed system (but goes, for example, into a river), then we must add **conservation issues** to the list of research topics. (Some members felt that no effluent in rivers should be tolerated, from either aquaculture or irrigation.)

Other researchable issues concerned **risk management**—the development of policy and techniques to minimise risks. Risks include those from **genetics**, **translocation of species** and **accidental introductions** to the natural ecosystem, and interactions involving **pathogens**. Pathogens may affect not only the aquaculture stock but also the natural ecosystem. Given that some pathogens are extremely difficult to detect and that their host-specificity is unknown, it is much more difficult to lay down a policy for disease management than it is for genetic issues. Release of only sterilised water might be feasible in some culture systems but probably not in the kinds envisaged here. Therefore, the whole issue of **disease management** was identified as a major research issue.

Although we had started with the case of shallow saline aquifers, and paid most attention to SBC systems, members felt that the general issues discussed would apply to the other two water resources. In the case of saline lakes, conservation issues would loom larger, and

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guidelines would be much like those already applicable to coastal mariculture operations. Use of deep aquifers would raise issues similar to those above, especially the question of preventing net addition of salt to the surface.

To conclude, it was felt that there need to be a **policy framework** and **guidelines for future investigations**. Specific points in such a policy should be that there would be *no export of salt from aquaculture to freshwater systems* and that aquaculture would add *no extra nutrient load to freshwater systems.* A policy framework containing those kinds of general specifications would then guide research into ways of meeting them.

Key opportunities for systems management of species, groups, areas and technologies

Session coordinator: Geoff Allan*

THE TABLE ON the following page is divided into three columns, one for each of the major sources of inland saline water in Australia. The first is saline lakes, usually shallow lakes with water that can vary greatly in salinity and can become extremely hypersaline at times. The second source is shallow aquifers. This includes rising saline groundwater, which is pumped into large, specially constructed evaporative ponds at some locations in eastern Australia in an attempt to prevent salinisation from reducing productivity in agricultural areas (this is a major problem affecting many of the large irrigation areas in south eastern Australia). Salinity of water from this source ranges from < 5 g/L to about 30–35 g/L. The third source of inland saline water is deep aquifers. These are often > 50 m below the surface. Although composition can vary from area to area, temperature and salinity are usually very stable.

This workshop plenary session endorsed the points in the table as being important opportunities for research on the saline lake, shallow aquifer and deep aquifer water sources. Those in *italic type* were felt to be particularly important. Another opportunity crossing the categories in the table is the compilation of a national inventory of available resources.

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Saline lakes	Shallow aquifers	Deep aquifers
Criteria for selecting species for use in feasibility studies		
Know how to culture—existing technology	*Know how to culture—existing technology. Ease of culture*	*Know how to culture—existing technology, including availability of fingerlings (intensive recirculation)*
Very euryhaline	*Euryhaline*	
Market value *—including sale as product or catch* *—recreational enhancement*	*Market value* *—including sale as product or catch* *—recreational enhancement*	Market value —including sale as product or catch —recreational enhancement
Production performance	*Production performance*	*Production performance*
Disease & pathogen translocation issues; broodstock availability	*Disease & pathogen translocation issues; broodstock availability*	*Disease & pathogen-translocation issues; broodstock availability*
Effect on environment		Effect on environment
Tolerant of environmental conditions, especially temperature	*Tolerant of environmental conditions, especially temperature (maybe less)*	
Reproductive performance (closed cycle on site)	Reproductive performance (closed cycle on site)	*Reproductive performance (closed cycle on site)*
	Salmonids, barramundi, prawns, freshwater crayfish; Australian bass, mulloway, black bream, silver perch, carp	*Barramundi, abalone, salmonids (temp. major consideration), flatfish, eels, snapper, aquarium species*
Not able to maintain breeding population		Hatchery supply of spat & fingerlings
Recreational species		
Carp, algae, artemia	Tilapia, abalone, artemia, aquarium species, oysters	Algae, flatfish
Technology		
Extensive (unlimited)	System—choice of design	Economical system design
Cage culture (limited)	Economics & pricing	Water & waste disposal or alternative use
	Production for sale versus fish-out	
Issues		
Property rights	Ability to use existing infrastructure	
Harvesting technology	Harvest technology	
Maintaining environment (conservation issues)	Waste disposal	Water and waste disposal

Research priorities within Australia

Session coordinator: Ned Pankhurst*

FOR THE PURPOSES of this workshop plenary session, research was considered in the general sense of information gathering as well as information generation. This reflects the fact that there is already a considerable data base available with respect to some questions; the challenges are to organise this and to generate new information. Priorities for this exercise were assessed against the following likely research issues (see 'Summation of outcomes of day 1', Pankhurst, these proceedings).

Physical resources

Characterisation of the resource

The task will vary from collation of existing data to new descriptions. Current data on chemical composition may not be adequate.

Availability

What volume and flow rates are available for aquaculture?

Infrastructure

Economic aquaculture operation may rest on the use of existing infrastructure for water delivery. Water resources need to be assessed in relation to this infrastructure.

Environment

Nutrient load management

Aquaculture generates waste water that is loaded with nutrients. It is not clear yet how compatible this is with existing use or management of saline ground water.

Pathogen management

Aquaculture operations bring the possibility of introduction of pathogens into inland waters. The research base for examining this concern is probably currently inadequate.

Salt

The cost of saline water management is often offset by the sale of salt as a product. Anecdotal reports by workshop participants suggest that this is not compatible with alternative water use, particularly with respect to nutrient loading. It is not clear yet whether this is a serious impediment to aquaculture development.

Other users

Aquaculture may have implications for other users (e.g. serial irrigation using low-salinity waters, or in relation to fixed structures in ponds or natural lakes). These have yet to be assessed.

Species

Species selection

The success of inland aquaculture will rest strongly with the selection of appropriate species. Species should be chosen for which there is already husbandry experience or technology available and that are appropriate for the range of environmental conditions at the site.

Performance assessment

Will the species chosen perform at a commercially acceptable level in inland waters? This is essentially unknown at present for all but barramundi at a single location.

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Technologies

System type and design

This is dictated largely by site constraints, but the transfer of generic aquaculture technology will be possible.

Harvest technology

A price advantage often rests on small advantages in product quality. Much of this is generated by harvest practice. Inland sites may offer special advantages in this regard.

Waste management

This involves creating solutions for the problems outlined under Environment, above.

Economic

Market research

This is essential.

Economic effects

The introduction of a new industry into depressed rural economies has potentially high economic and social effects. Market research and feasibility analysis will be needed.

Offshore implications

Aid

Management of inland saline waters is a large problem in Asia. Approaches for establishing aquaculture ventures based on the Australian experience could contribute markedly to the effects of Australian aid programs.

Technology export

Associated with the above point is the potential for export of technology developed in Australia. This will happen anyway if inland aquaculture is successful, so strategies for capturing the benefit need to begin with the early stages of project development.

Policy development

Slow evolution of management and development policies by regulatory authorities for mariculture has acted as a brake on development. This has not always been desirable. It would be helpful to a developing inland aquaculture industry if policy development could be encouraged in advance of commercial interest, rather than being driven by it. Policy initiatives in Australia will be relevant elsewhere.

Priorities

General discussion suggested that the order of priorities equates with the order of timing.

Short-term priorities

1. Collation of resource data and infrastructure availability.
2. Preliminary species selection.
3. Appropriate match of species with resources.
4. Preliminary performance assessment of target species.
5. Development of operational guidelines.
6. Development of feasibility and environmental management plans for specific operations.

Medium-term priorities

1. System design.
2. Optimisation of species performance.
3. Assessment and management of environmental effects.
4. Marketing strategies.
5. Disease management.

Longer-term priorities

1. Issues associated with increases in production scale.
2. Product refinement and delivery.
3. Mechanisms for technology transfer.

Operational guidelines for environmentally sustainable production from inland saline waters

Consideration of probable research priorities identified the need for a set of generic operational guidelines for all aquaculture developments using inland saline waters.

1. Operations should not in any way exacerbate existing inland salinity problems, and should preferably offset costs of of saline water management.
2. Release of waste water and nutrients from aquaculture operations should be minimised at

least to conform with water management regulations and at best to return water in as near as possible to its original state.

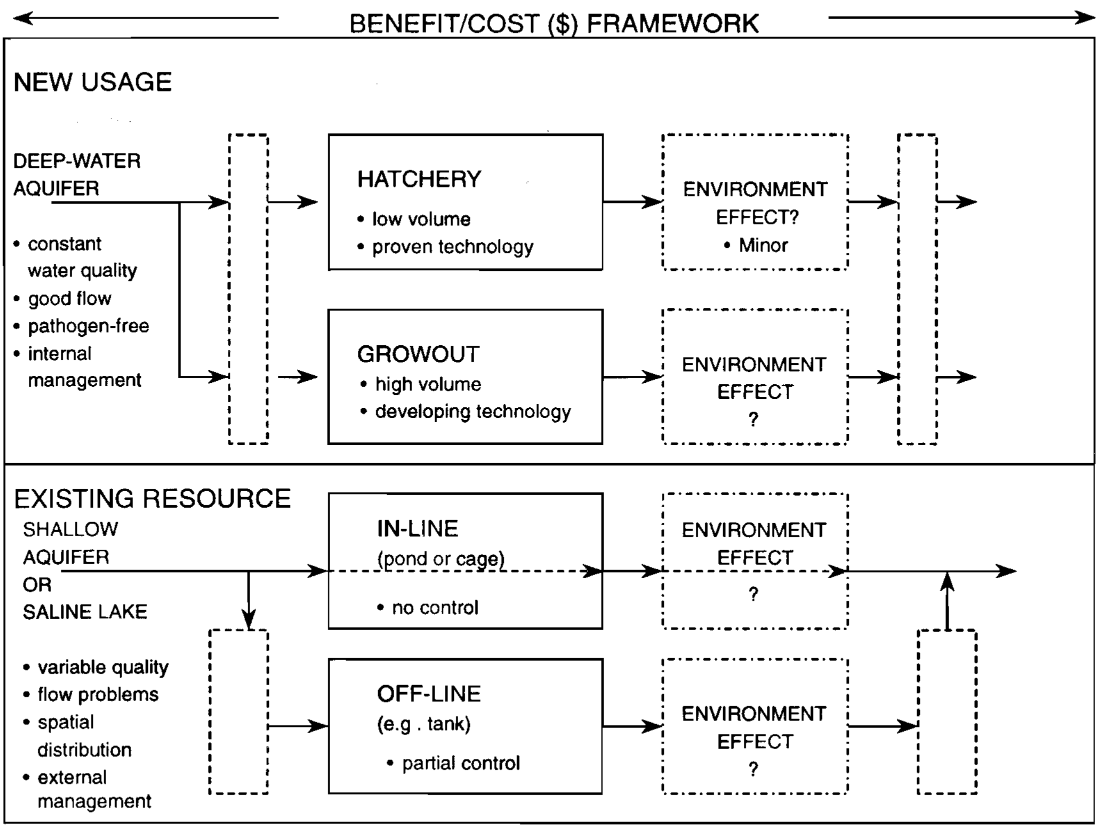
3. Operations will have to conform with existing regulations or policies for translocation. Sensible consideration needs to be given to whether inland operations might fall outside the range of conditions for which translocation policies were developed.
4. Operations must manage disease and contain pathogens in ways that at least meet legislation requirements and at best reflect current best practice in the industry.
5. Operations should include management programs for animal interactions and, in near-natural or natural waters, accidental release of farmed organisms.
6. It is highly desirable that inland saline aquaculture be integrated with existing multiple-use water strategies. This does not preclude single-use strategies where they comply with guideline 1 and where they confer a significant advantage for aquaculture over traditional techniques.

Coordinating mechanisms for research and development in Australia

Session coordinator: Patrick Hone*

THE RESEARCH TOPICS we discussed in this workshop plenary session can be split into two distinct groups: development of new inland saline water resources and development of existing saline water resources. As shown in Figure 1, these two systems have different R&D requirements to achieve their successful development. Further, the two groups are suited to different client bases. The development of new saline resources using deep aquifers is more suited to fish farmers, whereas existing saltwater exploitation is suitable for either land-based farmers wanting a diversification in

Figure 1: Inland saline water development for aquaculture.



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crops or water regulatory agencies. In both these cases the cost of development can be discounted against other economic considerations. It is important to note that both groups will employ the techniques of aquaculture, and so aquaculture should always be seen as a technique and not necessary equated with a type of person.

By identifying two groups with different R&D requirements it is possible to further determine an appropriate mechanisms for coordinating R&D. Before this is done, some of the limitations should be stated:

- Only limited research funds are available, from a variety of different sources (RIRDC, LWRRDC, ACIAR, CRC for Aquaculture, FRDC, state agencies, catchment authorities).
- Funding sources have no overall development plan for saline water use for aquaculture.
- Each development agency has different objectives that are not necessarily complementary.
- The saline water resource is diverse and is separated by vast distances, making coordination costly and difficult.
- People with aquaculture R&D skills are in limited supply because of the age of the industry.
- No R&D plan exists to guide funding agencies.

Several agencies have an interest in the development of inland saline water. Without the development of an R&D plan there exists the possibility of duplication of research. A collaborative approach will allow best usage of the limited funds available from the funding sources. To achieve this it is important to quantify the benefits and outcomes that each agency seeks in its strategy for the development of inland saline waters.

The following mechanism for coordinating research is suggested:

1. Document the available information and current R&D (this workshop).
2. Develop an R&D plan that identifies research priorities, research providers, economic benefits and clients (RIRDC and others). This plan should clearly identify a development schedule and responsible agencies.
3. Develop an integrated agriculture–aquaculture program and a standalone aquaculture program to use inland saline waters.

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