ALTERNATIVE STABLE STATES—A TOOL FOR MONITORING ECOSYSTEM CONDITION IN SOLAR SALTFIELDS

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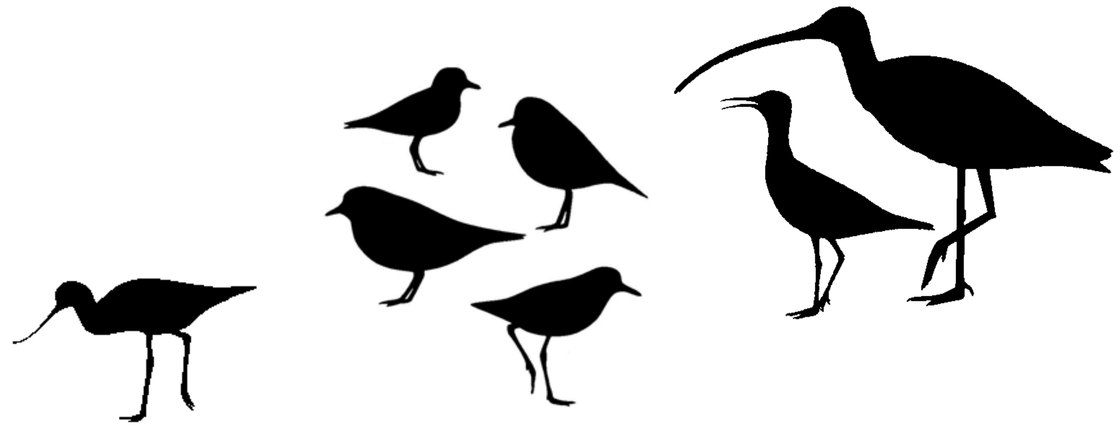
Background

Solar saltfields may appear, at first glance to be purely chemical facilities. However they support a distinctive biology that may impact on the production of salt for the benefit, or disadvantage, of the saltfield operator. Solar saltfield ponds are essentially a series of permanent saline wetlands and as such may exist in a range of 'stable states' or 'ecological regimes' (Sim *et al* 2006, Goldsborough & Robinson 1996)

In an ideal situation, the early ponds act as a brine purification wetland, removing nutrients and turbidity while the salinity is increased to the point where crystallisation occurs. At the other extreme the biology of the saltfield, fuelled by nutrients and disturbances, may give rise to an explosion of cyanobacteria that may produce a soluble slime that prevents the salt from crystallising (Coleman and White 1993, Roux 1996).

Monitoring saltfields biology can be a relatively expensive process for smaller operations and monitoring programs are frequently only initiated after a breakdown in field biology. Programs may be cut down, or discontinued, when conditions appear stable. As a result there may not be adequate warning of impending biological catastrophes.

Providing saltfield operators with tools to recognise the outward signs of the main saltfield pond 'stable states' can assist them in managing the biology of the field, and may provide them with advance warning that a closer examination of the field biology is called for.



Pond salinity	Stable state #	Stable state description		Flora/fauna characteristics	Physical & chemical characteristics
Eusaline to metasaline	1	Macrophytes and complex macroalgae		Much of the pond bottom supports marine angiosperms (eg seagrasses, widgeon grasses) and complex macroalgae with holdfasts and leathery blades. Low planktonic algae counts. Few benthic mat communities. Pond supports a wide variety of fauna including invertebrates, fish and bird life. There are relatively few bottom feeding fish, and an appropriate balance of herbivores and predators.	Water level remains relatively constant, with most of the pond relatively deep. The turbidity is consistently low, with water depth less than secchi depth. There is low irradiance to the benthos due to shading by macrophytes. Dissolved oxygen concentrations are high, nutrient concentrations are sufficient for growth of flora.
	2	Turfing algae and simple green macroalgae		Fine soft epiphytic brown and red macroalgae coat any seagrasses. Beds of simple green macroalgae including dense tangles of *Enteromorpha* spp. and *Chaetomorpha* spp, grow amongst, and over, any macrophyte beds. Patches of benthic mat communities are common in the shallows. Low-medium numbers of plankton. Fauna variety is reduced, with crustaceans and gastropods dominating and many filter feeders but with grazer numbers too low to control coating algae. Bottom feeding fish are common.	Water depth is changeable and relatively shallow, with turbidity often low, but variable. Benthic irradiance can be high. Occasional anaerobia in hot or still weather. Frequent measurably high nutrient concentrations in the brine, either from external input, disturbance events or as a result of flora/fauna death after anaerobia.
	3	Plankton		Flora is dominated by serial blooms of planktonic species of algae. Low benthic irradiance leads to loss of both epiphytic and macrophyte flora (eg seagrass and widgeon grass beds) resulting in extreme loss of faunal biodiversity.	Ponds are relatively deep and because of high turbidity the water depth exceeds secchi depth across much of the pond (benthic irradiance low). There are frequent catastrophic overnight anaerobic events and the brine has consistent measurably high nutrient concentrations.
Hypersaline	4	Benthic mat communities (BMCs)	4a (Oligotrophic)	Firm cyanobacterial benthic mat communities are attached to the pond benthos, with small populations of green flagellates (eg *Dunaliella* spp.) in the brine column providing feed for brine shrimp (eg *Artemia* spp and *Parartemia* spp.) that are harvested by shorebirds.	Clear water column (pond depth generally much less than secchi depth) and high irradiance in relatively shallow ponds. Nutrient concentrations are sufficient for growth of small populations of green planktonic algae (N:P ratio close to Redfield ratio) as well as the BMCs.
			4b (Eutrophic)	Loose benthic mat communities break up and float in the water column, with large numbers of planktonic cyanobacteria. Crustacean populations are variable. Little shorebird activity where the turbidity is high (hunting effort too large).	Water column is turbid. Pond depth over much of the pond is greater than secchi depth. Concentration of P frequently high, resulting in N-limited brine, favoured by cyanobacteria.

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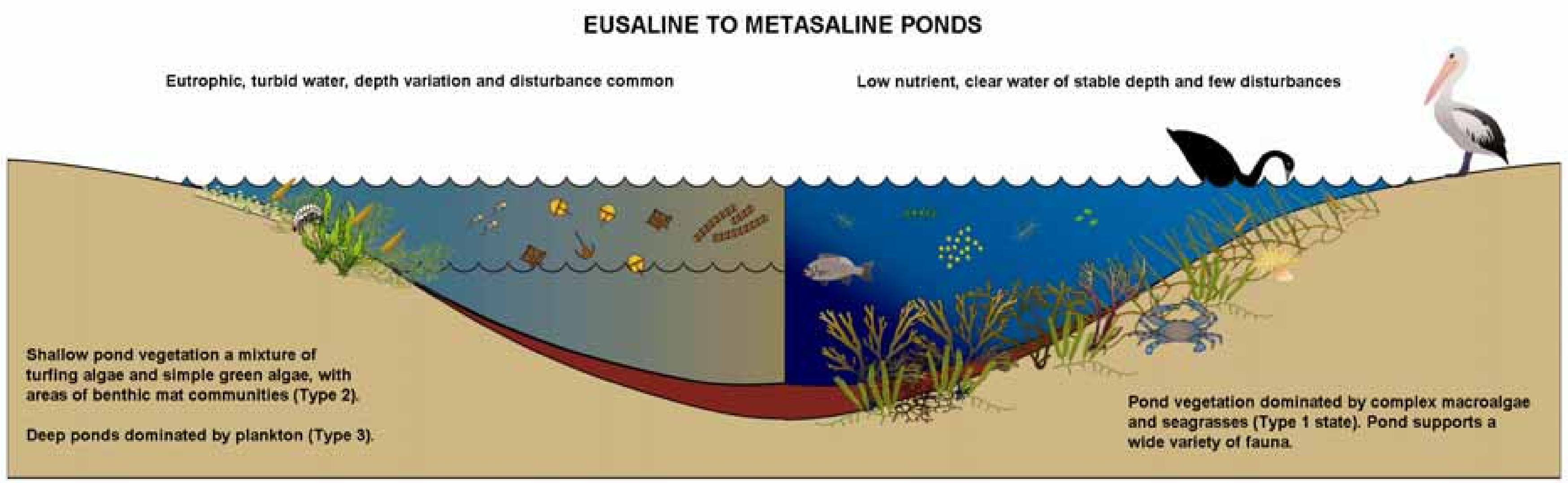
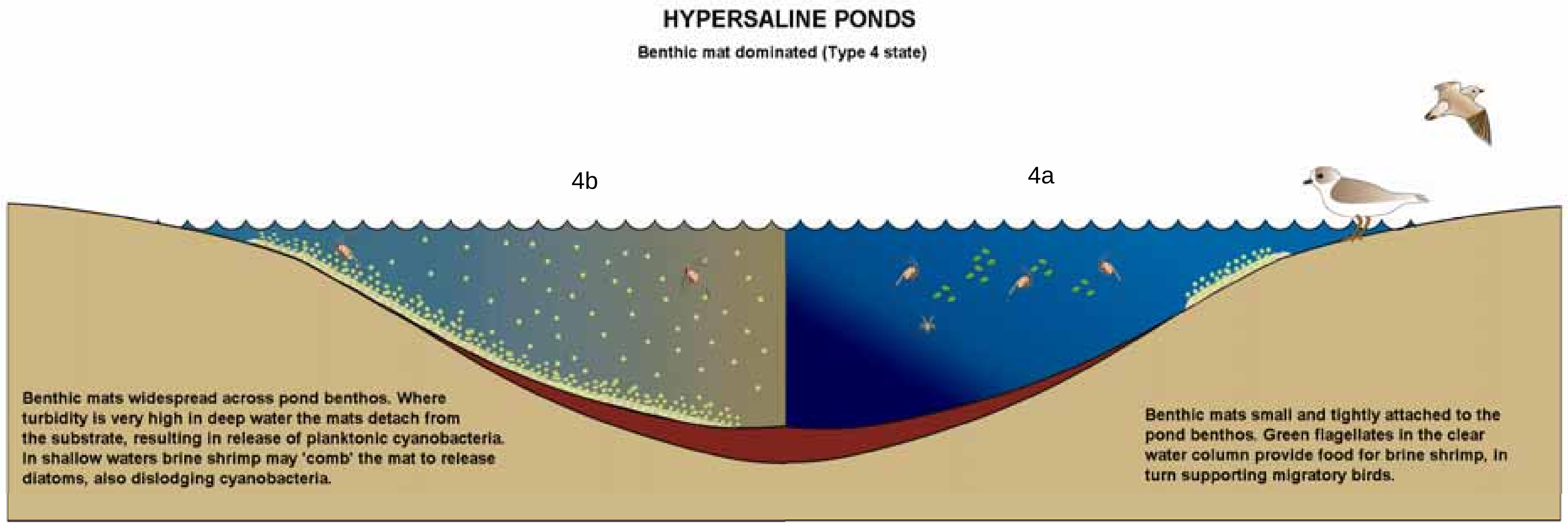
Which states are the ideal, for solar salt production?

Salt crystallises best from low viscosity, clean brines. Such brines are derived from series of ponds that have been maintained, in the majority of cases, in States 1 (lower salinity ponds) and 4a (higher salinity ponds).





Symbols for diagrams courtesy of the Integration and Application Network (ian.umces.edu/symbols), University of Maryland Center for Environmental Science.

What drives the change from one state to another?

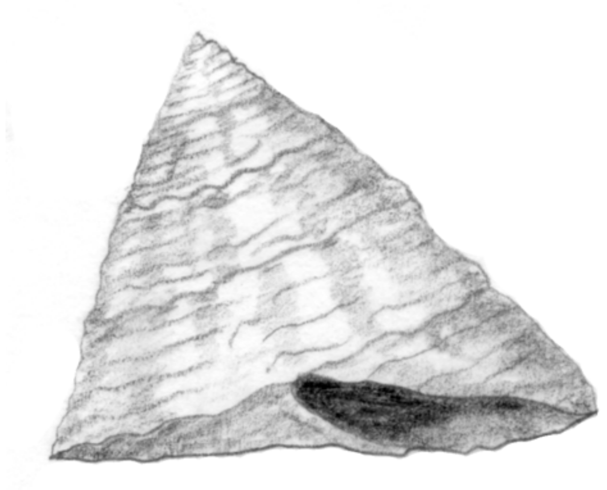
Driver		Results
Herbivory	High herbivory (grazing)	Reduced numbers of epiphytic coating algae, leading to increased health of macrophytes. High herbivore numbers support high predator (fish, birds) numbers.
	High herbivory (filtering)	Reduced numbers of planktonic algae, leading to clear waters and healthier macrophytes in lower salinity ponds or firmer benthic mats in hypersaline ponds. High herbivore numbers support high predator (fish, birds) numbers.
	Low herbivory (grazing)	Increased epiphyte loads decrease macrophyte health.
	Low herbivory (filtering)	Increased turbidity from plankton leads to decreased macrophyte health, or the breaking up of BMCs in hypersline ponds.
Disturbance	Waves, netting, benthic feeding fish	All these disturbances cause increased turbidity, which leads to decreased macrophyte health.
Trophic status	Relatively low, balanced N:P concentrations in the brine	Sufficient nutrients to maintain strong macrophyte growth and balanced ecology.
	Excess nitrogen	Blooms of coating algae and plankton (diatoms and assorted flagellates).
	Excess phosphorus	Blooms of cyanobacteria.
Water level	Increased depth	Lowers benthic irradiance and exacerbates the impacts of turbidity, but allows the water column to be minimally impacted by temperature and evaporation.
	Decreased depth	Increases benthic irradiance and minimised the impacts of turbidity, but may increase temperature and evaporation impacts on dissolved oxygen and salinity.
Salinity	Variation in salinity	Rapid changes in salinity in a pond may cause deaths of many organisms, resulting in 'slugs' of nutrients becoming available in the water column.

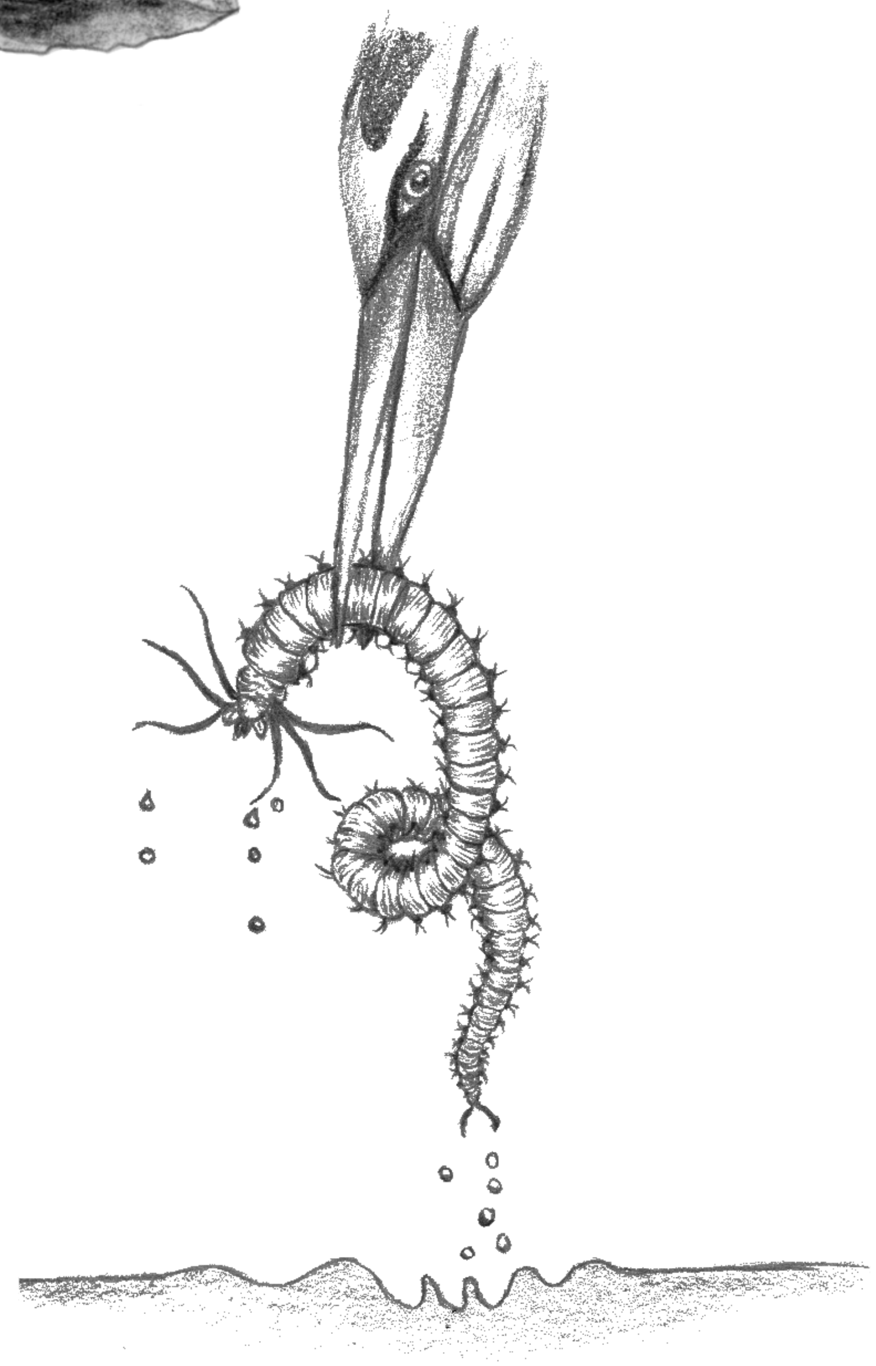
Using the Drivers as Tools

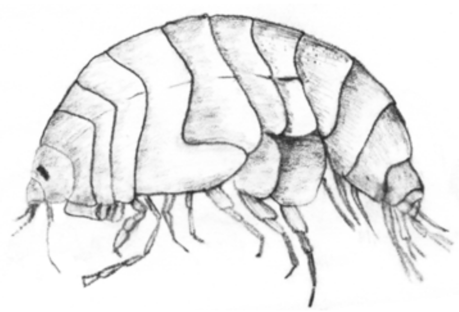
The simplest tools to manage the biological aspects of a solar saltfield are to assess each pond to determine the most appropriate depth and salinity of brine, and then manage the flow of brine to maintain those two parameters within as narrow a band as possible. This aspect of pond control is an essential part of salt production, and extending the process to include management of the biology is usually relatively simple and economical.

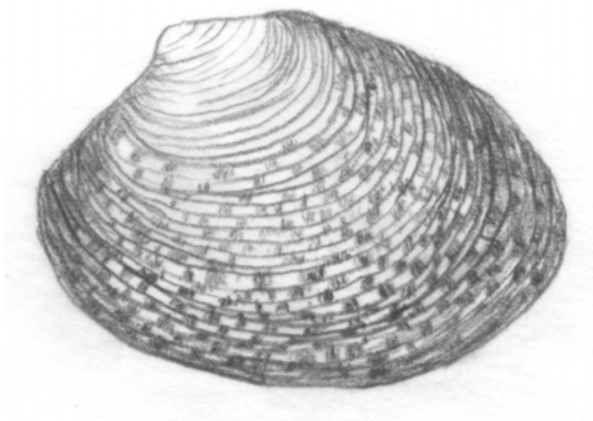
Controlling input of nutrients to the solar saltfield may be simple, or complex. Diversion drains or levees may be needed to ensure surface water runoff from neighbouring agricultural activities does not enter the ponds. Managing the biology to reduce anaerobic events and other disturbances will ensure that nutrient loads are not passed from one pond to another. Where the feed water for the field is eutrophic, there may not be much the saltfield operator can do, other than support efforts of their local authorities to improve the situation.

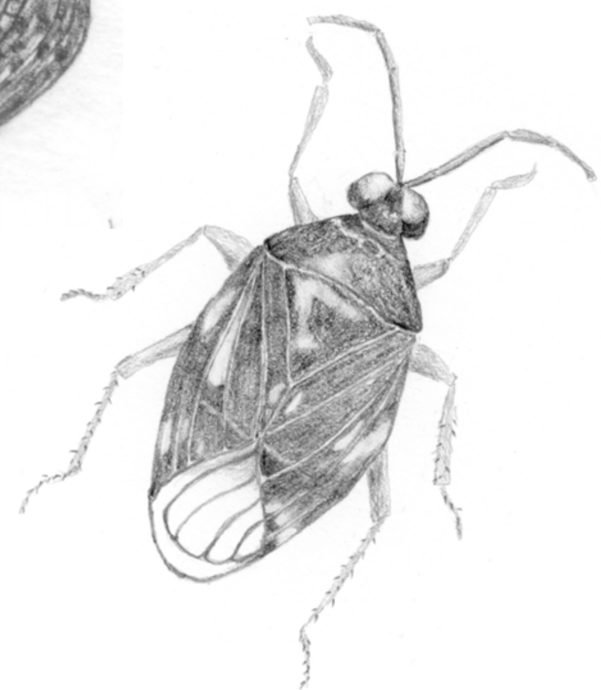
Finally, biomanipulation may be called for. The three common classes of organisms added to a solar saltfield are herbivores (fish and invertebrates), filter feeders and predators. The first class reduces epiphytic algae and/or macrophyte loads in the ponds, allowing better light penetration and stronger macrophyte growth. Filter feeders such as brine shrimp reduce planktonic turbidity, while predatory fish control herbivore numbers or may be used to reduce the impacts of benthic feeding fish in a field.











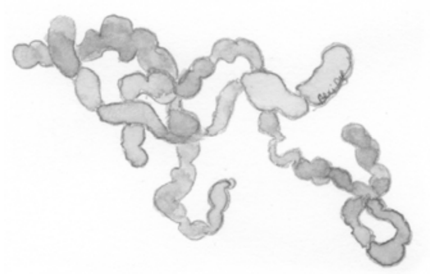
What should saltfield operators look for?

In the lower salinity ponds, the following are good indicators that the pond is maintaining State 1:

- the brine is clear and the pond bottom clearly visible
- extensive beds of seagrasses or widgeon grasses
- the leaves of the seagrasses are clean with no furry coatings
- there are no, or few, large tangles of fine hair-like green algae growing over the seagrass or widgeon grass beds
- herbivorous birds (eg black swans) are feeding on seagrasses and widgeon grasses
- fish eating birds (like pelicans) are actively hunting

In the higher salinity ponds, the following are good indicators that the pond is maintaining State 4a:

- the brine is clear and the pond bottom clearly visible
- any benthic mats are firmly attached to the pond bottom and are not showing signs of breaking up
- there are many brine shrimp visible
- there are flocks of small shorebirds feeding on the brine shrimp



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