# THE IMPACT OF INCREASING SALINITY ON FRESHWATER ECOSYSTEM: A REVIEW PAPER

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**ABSTRACT**

*Many freshwater ecosystems are currently threatened by increasing salinity caused by both natural occurence human induced salinity. Under natural condition, salt enters inland water system through groundwater intrusion and terrestrial run-of and salts buid up on the accumulated in the sediment due to high evaporation's rate. Under cultural salinisation or anthropogenically induced salinisation, salt enters the system through agricultural run-off and as a result of less freshwater flushing to low land river and wetland of which are affected sea water. For example, low flow regulation in majority of rivers in Australia has resulted in salt being accumulated in low land river and wetland ecosystems that affects freshwater biodiversity. In Indonesia, impact of increasing salinity over lowland area has been identified due to sea water level raising and salt water intrusion into inland water system, however, little is known about its impact on biodiversity of Indonesian Inland water. Increasing salinity in freshwater system is subject to ecological disturbance. Less tolerance species will be eliminated while more tolerant species will become dominant and in turn will develop saline habitat. This review reveals that the increasing salinity will induce a significant impact on freshwater ecosystem, ranging from decreasing biodiversity to loss of biodiversity.*

**Key words:** Salinity, freshwater ecosystem

**ABSTRAK**

*Banyak ekosistem air tawar yang saat ini mengalami gangguan sebagai akibat meningkatnya kadar garam pada peraiaran darat baik secara alami maupun akibat induksi manusia atau antropogenic. Secara alami, garam masuk ke perairan darat dapat terjadi sebagai akibat instrusi air tanah,* terrestrial run-off*, dan terakumulasinya garam sebagai akibat tingginya penguapan. Sedangkan secara antropogenic, kadar garam diperairan darat dapat meningkat sebagai akibat* run-off *dari lahan pertanian, dan sebagai akibat menurunnya atau rendahnya penggelontoran air tawar pada sungai dan lahan basah di dataran rendah yang terpengaruh oleh air laut. Sebagai contoh: kebijakan yang dilakukan di Australia untuk menahan aliran air tawar ke sungai dan lahan basah di dataran rendah telah mengakibatkan meningkatnya kadar garam di sungai-sungai dan lahan basah di daerah dataran. Di Indonesia, dampak meningkatnya salinitas telah teridentifikasi, utamanya sebagai akibat naiknya tinggi muka air laut dan instrusi air asin ke dalam sistem perairan darat, namun demikian pengaruhnya terhadap keanekaragaman hayati masih belum banyak diketahui. Meningkatnya kadar garam pada ekosistem perairan tawar dapat menyebabkan gangguan ekologis dan menurunnya keanekaragaman hayati. Species yang kurang toleran terhadap kadar garam tinggi akan tereliminasi dan species yang toleran akan menjadi dominan dan pada gilirannya akan membentuk suatu komunitas ekosistem air asin. Hasil telaah ini menyimpulkan bahwa peningkatan salinitas pada perairan daratan akan menyebabkan kerusakan ekosistem berupa penurunan keanekaragaman hayati sampai pada hilangnya keanekaragaman hayati pada eksositem perairan daratan.*

**Kata kunci:** Salinitas, ekosistem air tawar.

## INTRODUCTION

Salinisation of inland water ecosystem is defined as the increase of dissolved salt concentration (Williams 1987 cited in 1991). Increasing salinity is a serious threat to freshwater ecosystem and is becoming more serious due to environmental changes caused both by natural salinity and cultural salinity. A significant number of studies have shown that many freshwater ecosystems becoming saline particularly in coastal and semi arid region (Nielsen *et al.* 2007; Watt *et al.*, 2007). For example, in Australia, freshwater ecosystems are now becoming seriously threatened by increasing salinity that caused degradation in freshwater aquatic system and concern has been raised to the impact of salinisation on several freshwater systems in the region (De-Deckker 1983; Hart *et al.* 1991; Nielsen *et al.* 2003a). High salinity level impact on freshwater ecosystem is generally identified by loss of biodiversity particularly on less tolerant species (Halse et al., 2003). Even though some species develop high level of tolerance and acclimatisation, long term exposure may end with changes in community structure of the ecosystem. This paper presents a review on current knowledge towards the impact of salinity increases on freshwater ecosystem. The review is largely based on the study on the impact of freshwater salinisation on Australian freshwater system. Firstly, the paper addresses the history of inland water salinisation in Australia. Secondly, the impact of increasing salinity on freshwater biota is discussed and finally brief conclusions are presented.

### Salinity in freshwater ecosystem

Salinisation of inland waters occurs when the concentration of dissolved salts increases and exceeds the level of 3000 mg/L. Salt concentration of 3,000 mg/L is considered as the world average upper limit of water body considered as freshwater ecosystem. Thus, freshwater ecosystem often regarded as saline water when the salinity exceeds 3,000 mg/L, even though the Australian Water Resources Council (AWRC) has adopted up to a level of 5,000 mg/L as the upper limit (Hart *et al.* 1991; Boulton & Brock 1999). In Australia, salinity problems over freshwater system have existed over few decades since salt is a natural problem in this arid region. Salt enters freshwater system by the process of weathering of rock, groundwater intrusion and terrestrial and agriculture run-off. Water that is used for irrigation naturally contain salt and when the water goes due to high evaporation's rate and/or being absorbed by plants, salt will be accumulated in land surface and enters water body by run-off and leaching.

In addition, low flow condition in many river systems in Australia such as the Murray River, where the water flow has been regulated, that resulted in reduced of high frequency of freshwater flushing to the river pool and wetland system contributed to the increasing of salts concentration in riverine pools and wetlands (Nielsen *et al.* 2003b). Consequently, concentration of salt in the river and wetland system will gradually increase over time and may no longer support freshwater life in the ecosystem. In regard to salinity problems, significant literatures have shown a growing awareness concerning the increasing salinity and its impact on Australian inland aquatic system (De Deckker 1983; Williams 1984; De Deckker & Williams 1986; Bond et al., 2008). For example, the current interest towards salinity impact on Australia's water way is given to the lagoon ecosystem of the Coorong and Lower Lakes in South Australia which currently experiencing increasing salinity up to three to five times of sea water salinity (Lamontagne *et al.* 2004).

Given that many areas of other countries and regions are subjected to rising salinity due to salt water intrusion, extensive agriculture practices and climate change, this study indicates a promising area for research related to the impact of rising salinity on freshwater ecosystem in other regions. For example, the impact of increasing salinity on freshwater ecosystem is less known and under studied in South East Asia including Indonesia where many of its coastal lakes and low land rivers are subjected to rising salinity due to salt water encroachment to the groundwater especially in the area where the groundwater level is generally below sea level (Schmidt *et al.* 1988; Nur *et al.* 2001). As an archipelago country many low land areas in Indonesia are subjected to sea water inundation due to rising sea water level (Marfai, 2009) and could potentially affect low land inland water and estuaries ecosystems. Previous study on salinity´s increasing impact in Indonesia were mainly focused only on salinity´s impact on agricultural land and rice cultivation (Chaerun *et al.* 2009) while detailed studies on its impact on freshwater ecosystem have not yet been made.

**Response of freshwater species to rising salinity level**

Salinity is an important factor determining the presence and dominance of aquatic organisms. A number of evidence showed that freshwater species do not well adapted to hyper saline system and as a result, increase in salinity level has drastically altered freshwater biota community (Green & Mengestou 1991; Brock and Shiel 1983; Boon 2000; Brock *et al.* 2003; Brock, Nielsen & Crossle 2005). In addition, a study by Nielsen *et al.* (2008), show that increasing salinity in freshwater ecosystem has caused significance reduction in the emergence of wetland plants and zooplankton when the seeds and eggs are exposed to a high salinity environment. Similarly, reduction in species diversity has been identified in freshwater wetlands zooplankton that exposed to high salinity level (Gonçalves *et al.* 2007). In line with this, high salinity has also been known influenced plants growth and death caused by the toxic effect of excess ions and water deficiency due to hyper saline environment (Greenway and Munns., 1980 cited in James *et al*., 2003).

Increasing salinity may influence freshwater community in three different approaches. First of all, it may cause toxic effect which sometimes can have a direct lethal effect; second of all, it may cause changes in physiological behaviour of the freshwater species; and third of all, increasing salinity may lead to loss of freshwater species habitat. In other words, freshwater species response toward different salinity level can be in the level of tolerance, acclimatisation or avoidance. As revealed by James *et al* (2003), acclimatisation is one aspect of tolerance while avoidance can lead to habitat selection that allowing the freshwater species to select their preference habitat or to form resting eggs that allowing them to re-establish whenever the salinity level is suitable.

Acclimatisation of organisms toward salinity changes depends on the nature of the salinity increase in term of rates, duration, and/or time scale; periodically, seasonally or suddenly changes. Bailey *et al.,* (2003 dan 2004) found that slowly increasing salinity (10 to 50% of initial concentration) might allow some species to acclimatise and tolerate increasing salt concentration and probably reach their new salinity threshold. On the other hand, suddenly large increased salinity (100%-200% of initial level) may cause significant lethal impact.

***Salinity impact on Invertebrates***

Study by Hart *et al* (1991) showed that adverse affects have been identified on invertebrates once salinity exceeds 1,000mg/L. Studies conducted across Australia's freshwater wetlands have investigated the loss of diversity when salinity increases (James *et al*., 2003; Nielsen *et al.* 2003b; Schallenberg *et al.,* 2003; Boulton and Lloyd 1992). Internal ionic concentration of most freshwater invertebrates is ranged from 1,000mg/L to 15,000mg/L and they maintain this concentration in constant level by developing osmoregulatory mechanism (Hart *et al* 1992). However, the species will no longer be able to maintain its osmoregulatory system once salinity exceeded its tolerance level. According to Hart *et al* 1992, most freshwater invertebrates will fail to maintain this osmoregulation system at salinity level of 9,000mg/L.

Different species will have different respond towards salinity changes. For example, zooplanktons have developed ionic balance in their cells and tissue and it is important in determining their sensitivity and tolerance to salinity regimes. According to Hart *et al* (1991), zooplankton tolerance towards salinity regimes is determined by the ability of zooplankton to regulate its internal osmotic concentration against external gradient. Freshwater zooplanktons have significantly lower ions concentration in their body fluid than that of marine zooplanktons. Consequently, ion concentration is to be lost by diffusion while, on the other hand, gained water by osmosis. Therefore, it can be said that freshwater zooplankton are hyper-osmotic regulator. However, as the salinity is increased beyond which they can maintain constant ions concentration, the zooplankton tend to take more ions and lose more water until eventually can no longer support their cells function and caused death.

### *Salinity impact on Plants*

Generally, freshwater plants are not well adapted in high salinity level and will be replaced by more salt tolerant plants as salinity exceeds 4,000mg/L. A study by Brock 1981, 1985,1986 as cited in Nielsen *et al* (2003a) showed that when salinity level above 4,000 mg/L, non-halophytes such as *Myrioplhyllum* are replaced by other more saline tolerant plants such as *Ruppia* and *Lepilaena*. In addition, seeds bank assessment from several freshwater wetlands in Australia indicated that constantly increasing salinity has significant impact on the successful of seeds germination which is reflected on a low diversity and abundance once salinity exceeds 1,000mg/L. Low order aquatic plant, such as microalgae are known to be less tolerant to salinity increases. Hart *et al* (1991) reported in their study that most of microalgae could not survive when salinity increases up to 1,000mg/L.

### *Salinity impact on Fish*

Most Australian native fish are originally of marine and/or diadromous ancestry (migrating between freshwater and the sea during their life cycle). Hence, they appear to be more tolerant inreasing salinity (Chessman and Williams 1974; hart *et al*, 1991; Williams and Williams 1991; Whiterod 2001). For example, the groups such as Hardyheads *(Craterocephalus stercusmuscarum (*Fly-specked Hardyhead*)*, gudgeons (Hypseleotris compressa (Empire Gudgeon, Carp Gudgeon), *Mogurnda adspersa* (Purple-spotted gudgeon), gobies and catfishes that have of marine ancestry are more saline tolerant. Toxicity assessment conducted by Hart *et al* (1991) found the LD 50 of salinity level on Hardy head family; *Craterocephalus stercusmuscarum fulvus* and *Retrofinna semoni* at 43,700mg/L and 59,000 mg/L respectively which is high level of tolerance. Though adult fish have been known to develop high level of tolerance regarding increasing salinity, juveniles and eggs of some freshwater species are vulnerable (O'Brien, 1995 cited in Nielsen *et al.* 2003b). For example, a study by James *et al*., (2003) stated that the survival rate of Macquarie perch eggs is only 50% once exposed to 3,000mg/L salinity.

## DISCUSSION AND CONCLUSION

The article has highlighted a general overview of salinity impact on freshwater ecosystem. It is generally accepted that freshwater ecosystems are regarded as saline ecosystem when salinity level exceeds 3,000mg/l. Australia has adopted higher limit, 5,000mg/L as the upper limit, which is almost doubled the world average upper limit (Hart *et al.* 1991; Boulton & Brock 1999). However, the data available about the salinity impact is largely based on research and study in low land arid river and wetlands in Australia where increasing salinity already occurs for decades. Thus, information on the sensitivity of inland water organisms to elevated salinity discussed in this paper might not be applicable to other regions where salinity increases is less constant or in the case of sudden salinity changes. The reason for this is that the Australian freshwater ecosystems have already exposed to increasing salinity for many decades and the system might have already developed more salt tolerant species and have higher salinity threshold. In Indonesia, very little attention is given to the study of the impact of salinisation on inland water ecosystem although it is known that many of its coastal lakes and low land rivers are subjected to rising salinity due to salt water encroachment.

For the same reason, when salinity of 1,000 mg/L in arid low land river has been observed to undergo minor ecological impact (Nielsen *et al.* 2003b), it does not necessarily mean that freshwater ecosystems with salinity below 1,000mg/L are good since other systems in different regions may undergo different salinity threshold; hence, its sensitivity will also be different. In addition, information that does exist for salinity impact on freshwater species is largely observational on adult individual level. In fact early life stages are known to be more vulnerable to environmental changes including salinity regimes. Yet little is known about the effect of elevated salinity on eggs and/or juvenile stage and community level as well as the impact on freshwater food chain. Identifying the impact on early life stage is very important in order to predict the long term impact on community. Even if adult species developed more salt tolerant, the long term impact assessment might cause species lost due to discontinue growth and life cycles which in turn will affect the ecosystem tropic balance.

From management implication, significant effort has been done to manage salinisation as well as to reduce the impact of inland water salinisation on freshwater ecosystem. As for Australian case, freshwater flow to the salinised wetlands have been regulated allowing water to flow to the wetlands and thus the salinity of the lowland wetlands ecosystem can be maintain (Goodman et al, 2010) . Environmental flow regulation is also being applied to allow a significant flow of freshwater to be discharged in to lowland salinised wetland, allowing freshwater flushing processes in the wetland in order to reduce salinity. Overall, it is possible that some aspect might be either overlooked or only shortly discussed in this review paper. Therefore, a more comprehensive review is needed to fill the gap that uncovered in this paper.

## REFERENCES

Bailey, SA, Duggan, IC, Van-Overdijk, CDAv, Jenkins PT, MacIsaac HJ., 2003. Viability of Invertebrate Diapausing Eggs Collected from Residual Ballast Sediment. *Limnology and Oeceanography* 48: 1701-1710.

Bailey, SA, Duggan, IC, Van-Overdijk, CDA, Johengen, TH, Reid, DF & Macisaac, HH., 2004, 'Salinity Tolerance of Diapasuing Eggs of Freshwater Zooplankton, *Freshwater Biology,* 49 : 286-295.

Bond NR, Lake PS, Arthigton AH., 2008. The Impactof Drought on Freshwater Ecosystem: An Australian Perspective. *Hydrobiologia* 600: 3-16.

Boon, PI., 2000, *Biological Impact of Changes to Water Level and Salinity in the Corong*.

Boulton, AJ & Brock, Ma., 1999, *Australian Freshwater Ecology*, Gleneagles Publishing, Australia.

Boulton AJ & Lloyd LN., 1992. Flooding Frequency and Invertebrate Emergence from Dry Floodplain Sediments of the River Murray, Australia. *Regulated Rivers: Research & Management,* 7: 137-151.

Brendonck L., De-Meester L., 2003. Eggs Banks in Freshwater Zooplankton: Evolutionary and Ecological Archives in the Sediment. *Hydrobiologia,* 491: 65-84.

Brock, MA, Nielsen, DL & Crossle, K., 2005, 'Changes in Biotic Communities Developing from Freshwater Wetland Sediments Under Experimental Salinity and Water Regimes', *Freshwater Biology,* 50 (8): 1376-1390.

Brock, MA, Nielsen, DL, Shiel, RJ, Green, JD & Langley, JD 2003, 'Drought and Aquatic Community Resilience: the Role of Eggs and Seeds in Sediments of Temporary Wetlands', *Freshwater Biology,* 48 (7): 1207-1218.

Brock MA., Shiel RJ., 1983. The Composition of Aquatic Communities in Saline Wetlands in Western Australia. *Hydrobiologia* 1005: 77-84.

Chaerun, SK, Whitman, WB, Wirth, SJ & Ellerbrock, RH., 2009, 'Chemical and Mineralogical Characterisation of Agricultural Soils Iinundated by the December 26, 2004 Tsunami After Intrinsic Bioremidiation in Banda Aceh, Sumatera Island, Indonesia', paper presented at the National Meeting of the American Society of Mining and Reclamation, Billings, MT, May 30 - June 5.

De-Deckker, P 1983, 'Australian Salt Lakes: their History, Chemistry, and Biota — a Review', *Hydrobiologia,* vol. 105 (1): 231-244.

De Deckker, P & Williams, WD (eds), 1986, *Limnology, the Study of Inland Waters: a Comment on Perceptions of Studies of Salt Lakes, Past and Present.*, CSIRO, Melbourne.

Goodman AM, Ganf GG, Dandy GC, Maier HR, Gibbs MS., (2010) The Response of Freshwater Plants to Salinity Pulses. *Aquatic Botany,* 93: 59-67.

Gonçalves, AMM, Castro, BB, Pardal, MA & Gonçalves, F., 2007, 'Salinity Effects on Survival and Life History of Two Freshwater Cladocerans (Daphnia Magna and Daphnia Longispina)', *Ann. Limnol. - Int. J. Lim.,* 43 (1): 13-20.

Green, J & Mengestou, S., 1991, 'Specific Diversity and Community Structure of Rotifera in a Salinity Series of Ethiopian Inland Waters', *Hydrobiologia,* 209 (2): 95-106.

Halse SA., Ruprecht JK., & Pinder AM., 2003 Salinisation and Prospects for Biodiversity in Rivers and Wetlands of South-West Wester Australia. *Australian Journal of Botany,* 51: 673-688.

Hart, B, Bailey, P, Edawrds, R, Hortle, K, James, K, McMahon, A, Meredith, C & Swadling, K., 1991, 'A review of the Salt Sensitivity of the Australian Freshwater Biota', *Hydrobiologia,* 210 (1): 105-144.

James, KR, Cant, B & Ryan, T., 2003, 'Responses of Freshwater Biota to Rising Salinity Levels and Implications for Saline Water

Management: a Review', *Australian Journal of Botany,* 51: 703-713.

Lamontagne, S, McEwan, K, Webster, I, Ford, P, Leaney, F & Walker, G., 2004, *Coorong, Lower Lakes and Murray Mouth*, Csiro.

Marfai, MA., 2009, *Impact of Climate Change in Coastal Area: a Vulnerability Assessment of Coastal Inundation Due to Sea Level Rise in Central Java Indonesia*, IOP Publishing, IOP Conference Series: Earth and Environmental Science.

Nielsen, DL, Brock, M, Crossle, K, Ken, H, Healey, M & Jarosinski, I., 2003a, 'The Effect of Salinity on Aquatic Plant Germination and Zooplankton Htching from Two Wetland Sediments', *Freshwater Biology,* 48: 2214-2223.

Nielsen, DL, Brock, MA, Petrie, R & Crossle, K., 2007, 'The Impact of Salinity Pulses on the Emergence of Plant and Zooplankton from Wetland Seed and Egg banks', *Freshwater Biology,* 52 (5): 784-795.

Nielsen, DL, Brock, MA, Rees, GN & Baldwin, DS., 2003b, 'Effect of Increasing Salinity on Freshwater Ecosystem in Australia', *Australian Journal of Botany,* 51: 655-665.

Nielsen, DL, Brock, MA, Vogel, M & Petrie, R., 2008, 'From Fresh to Saline: a Comparison of Zooplankton and Plant Communities Developing Under a Gradient of Salinity with Communities Developing Under Constant Salinity levels', *Marine and Freshwater Research,* 59 (7): 549-559.

Nur, Y, Fazi, S, Wirjoatmodjo, N & Han, Q., 2001, 'Towards Wise Coastal Management Practice in a Tropical Megacity--Jakarta', *Ocean & Coastal Management,* 44 (5/6|): 335-353.

Schallenberg, M, Hall, CJ & Burns, CW., 2003, 'Consequences of Climate-Induced Salinity Increases on Zooplankton Abundance and Diversity in Coastal Lakes', *Marine Ecology Progress Series,* 251: 181-189.

Schmidt, G, Soefner, B & Soekardi, P., 1988, 'Possibilities for Groundwater Development for the City of Jakarta, Indonesia', Paper Presented at the Hydrological Processes and Water Management in Urban Areas, Duisberg.

Watt, S, García-Berthou, E & Vilar, L., 2007, 'The Influence of Water Level and Salinity on Plant Assemblages of a Seasonally Flooded Mediterranean Wetland', *Plant Ecology,* 189 (1): 71-85.

Williams, WD., 1984, *Salinity as a Water Quality Criterion and Determinant in Australia*, Departement of Resources and Energy, Canberra.