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A REVIEW ON MACROINVERTEBRATES' PHYSIOLOGICAL RESPONSE TO REGULATED STREAM FLOW

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ABSTRACT

Short rainfall, elevated rates of evaporation, exhaustion of underground water levels and highly inconsistent stream flow regimes have encouraged the construction of big dams and other water regulating infrastructure development resulting in degradation of river ecosystems. These major changes transform and reduce the biological composition of rivers, isolating populations of aquatic life and their habitats within a river. Invertebrates account for roughly 95% of all animals, so it is important to understand their physiological response to various stressors related to changes in flow regime. This review summarizes the ecological impact of dams in river ecosystems, specifically on macro-invertebrates and their physiology and highlights potential stressors responsible for environmental disruption.

Key words: dams, flow, macro-invertebrates, stress

INTRODUCTION

The objective of the present review is to examine the literature and summarize the responses of ecological components in particular macro-invertebrates and their physiology to the effects of changes in various physical parameters due to construction of a dam. Studies included in this review range from peer-reviewed literature to un-refereed reports. The focus of the review is the effect of flow modification, thermal pollution & changes in water quality on macro-invertebrates composition and their response to stress.

To deal with the greater demands on the world's freshwater barriers are constructed for power generation, flood control and irrigation, resulting in degradation of river ecosystems [1,2,3,4]. River systems are affected severely by the disruption of the natural course and flow, altered water temperatures, redirection of river channels, transformation of floodplains, and disruption of river continuity [5,6,7,8,9,10]. These major changes often transform and reduce the biological composition of rivers, isolating populations of aquatic life and their habitats within a river [11,12]. Downstream effects include alteration of the natural flow regime, which is a function of the magnitude, frequency, duration, timing and rate of change of hydrological conditions [13]; water temperature regime, and physical habitat, all of which leads to decreased aquatic ecosystem health. Dams impose a *lentic* habitat within a *lotic* system [14] and aquatic communities must adjust suddenly to the changes in physical, chemical and biological attributes of riverine systems to those of lacustrine systems [15] with some taxa decreasing or even disappearing when a lentic system is imposed upon them (e.g. Baetidae and Simuliidae) [16] while some others may increase [17]. Macroinvertebrate species diversity below the dam was only half of that in the pristine catchment area above the dam while Ephemeroptera, Plecoptera and Trichoptera diversity and abundance dropped to almost zero as a result of the impoundment [18]. A study of aquatic Coleopterans at a reservoir near Cape Town indicated a negative effect on the aquatic fauna from the impoundment, reducing certain endemic and threatened species of Elmidae, Dryopidae and Hydraenidae by 73% [19]. The dam has a significant impact on the composition of macroinvertebrates just above the dam site and small reductions in discharge, seems to have small or no impact on the macroinvertebrates fauna downstream the dam [20]. However, little is known about the effects of dams further downstream [21].

The cellular stress response protects organisms from damage resulting from exposure to a wide variety of stressors, including elevated temperatures, ultraviolet (UV) light, trace metals, and xenobiotics [22]. The stress response entails the rapid synthesis of a suite of proteins referred to as stress proteins, or heat-shock proteins, upon exposure to adverse environmental conditions. These proteins are highly conserved and have been found in organisms as diverse as bacteria, molluscs, and humans. it is apparent that stress proteins are involved in organismal adaption to both natural and anthropogenic environmental stress, and that further research using this focus will make important contributions to both environmental physiology and ecotoxicology, while Endocrine disruptions in aquatic insects have been studied [23, 24, 25]. The early literature on the effects of dams, especially in North America has been reviewed [26,27,28]. The ecological effects of low flows on chalk streams have been discussed [29]. Ecological changes in wetlands of NSW has been reviewed [30].The ecological effects of large dams in Australia with inclusion of some discussion of modified flow regimes also reviewed [31]. Changes over time in four Australian wetlands: Macquarie Marshes, Chowilla Floodplain, Gwydir wetlands and the Moira marshes of Barmah forest have been described [32]. The impact of river regulation and flow modification in the Murray-Darling Basin has been reviewed [33]. The effects of irrigation on wetland systems, namely water abstraction and return of polluted water, although their review covered mainly un-refereed reports from Europe, North America, Africa and Australia has been discussed[34]. However, only a few studies provided quantified information on flow change and ecological response that could be compared between studies and included in analysis of relationships and thresholds.

MATERIALS AND METHODS

Abstracts, Research papers and citations were collected by searching databases for the terms like Flow modification, Flow alteration, Flow threshold, Environmental flow, Flow regulation, Macro-invertebrates' physiology etc. Several database viz Bioscience, Journal of insect conservation, Biodiversity conservation, Journal of fisheries and aquatic sciences, American fish society, Australia ecology, Canadian Journal of Zoology, Journal of Fresh Water Ecology, Ecology of regulated Streams, Oslo university press publications, Cambridge University press publications, University of California press publications, Fresh Water Biology, Journal of Animal Ecology, Journal of North American Benthological Society, Regulated River research & Management, CSIRO Journals, Hydrobiologia & Wiley Journals were searched. In addition, reference lists from the review papers and reports were checked for additional relevant papers. Also, the reference lists from all the reviews, reports and research papers examined were checked for other relevant publications.

RESULTS AND DISCUSSION

Some of the Important studies done to analyze the effect of various physical parameters which greatly influence the composition of macroinvertebrates composition and physiology in the altered rivers are as follows:-

1. Sediment

Rivers play a paramount role in shaping the landscape by selectively eroding, transporting and depositing sediments on the land in their journey towards the ocean [43]. These sediments range from fine clays up to large boulders. Fine sediments are a category of sediments consisting of fine sand (<2000 to >62 μm), silts (<62 to >4 μm), and clays (<4 μm). Fine sediments occur naturally in streams but are considered a pollutant when they are in excess of natural levels [21]. Sediments are considered one of the top stream pollutants by the U.S. Environmental Protection Agency (EPA 2004). Excess fine sediments are primarily human-induced and can result from disturbances such as dams, surface mines and construction activities [44] and land use relating to agriculture, forestry, and residential development.

Dams strongly influence sediment transport because they often modify the natural discharge regime [10,13]. Dams disrupt the often natural highly variable flow regime, replacing it with a less variable low discharge [7, 46, 47]. Reduced peak flows hinder sediment transport capacity and competence [48]. As a result, reaches downstream of dams can accumulate fine sediment deposits without natural scouring. Fine sediment introduced from downstream tributaries may also accumulate on the bed if reservoir storage has sufficiently reduced the river's transport capacity [49]. The addition of fine sediment to a stream alters the substrate composition by filling in interstitial spaces and coating surfaces which affects substrate suitability for aquatic organisms [48, 50, 51]. Fine sediments can increase insect drift, deposit on respiratory structures, and reduce dissolved oxygen availability [43, 44, 50, 52]. Macroinvertebrates density and substrate relationships in a small, high plains stream in Montana has been studied and changes to the macroinvertebrate assemblage from an increase in fine sediment have been indicated [53]. Fine sediment deposits that resulted from nearly constant regulated flow year around have been studies [21].

Riparian or dryland plants invade dry ground and in-channel islands [54]. Salmon populations in the Mackenzie River, Oregon, have decreased by 50% as a result of lack of spawning habitat [48]. Macroinvertebrate community composition was altered in conjunction with sedimentation and changes to channel morphology [55]. A substantial reduction in the area, depth and volume of aquatic habitat resulted in a 54% increase in primary production and a multifold increase in secondary production [56]. Ephemeroptera, Trichoptera and Plecoptera can be lost as soon as a dam is built, to be replaced by high densities of Dipterans [57].

2. Temperature

Temperature increases below dams have been given little attention [58, 59, 60, 61]. A dam causes elevated water temperature due to a reduction in water flow and the presence of a standing pool of water immediately above the dam wall. The warming of the water is also the result of reduced canopy cover from dieback of the natural overhanging vegetation and increased sunlight penetration. The increased sunlight also causes an increase in microbial and algal activities. These effects spill over and increase mean water temperature below the dam. In Hawaii, canalization and removal of the riparian canopy cover resulted in higher water temperatures, increased daily temperature fluctuations, increased siltation, and decreased substrate size [62]. Bio-energetic studies indicate a strong positive relationship between feeding rates and metabolism with temperature for both fish and insect communities [63, 64]. Increased metabolic rate carries with it a need for increased levels of food quantity or quality in order to maintain growth and survival rates

[61]. Also, temperatures must not exceed the biological preferences of typical cold-stenotherms (i.e. 20 °C) if cold-water fauna are to prosper downstream [65, 66, 67].

It has been suggested that impacts on temperature are restricted to the area of stream directly below the impoundment and that temperatures quickly equilibrate with the air [68]. Without some cooling factor (e.g. groundwater recharge) downstream, however, reaches with increased summer temperatures are not able to shed added heat during the summer, but continue to warm according to normal stream processes [69]. This heat loading has the potential to maintain downstream temperatures above the range that cold-water stenotherm prefer. Factors influencing temperatures below dams include the size of impoundment (specifically depth and surface area), residence time, whether or not the impoundment stratifies, and the release depth [59, 64, 68]. Another important factor is the amount of groundwater coming in upstream and downstream of the dam [65, 66]. Both temperature and diurnal temperature fluctuation were altered below a surface-release of dam, but that diurnal temperature fluctuation returned to upstream values with increasing distance downstream of the dam [58]. Temperature change, therefore, may be a more consistent indicator of thermal alteration for longer distances downstream.

Stream habitats change from headwater reaches to the mouth, and dams are known to alter certain habitat parameters so that the normal continuum is disrupted. Mean summer temperature was the only stream habitat parameter that was significantly different between upstream and downstream sections away from what would be predicted for unregulated streams. In general, mean summer temperature was substantially increased downstream by these small, surface release facilities. These increases in temperature were maintained at least 2–3 km below the dams. Downstream communities responded to warming below dams with shifts in the macroinvertebrate community [70].

3. Dissolved Oxygen

Decreased levels of dissolved oxygen influence benthic macroinvertebrate assemblages [71]. Dissolved oxygen values were lowest in the low-flow, downstream areas, where invertebrate diversity was also lowest [18]. Macroinvertebrates may respond to oxygen deficiency in several ways [72]. Possible implications of oxygen deficiency Species living in high altitude streams should have adapted to the oxygen conditions, whereas non-adapted species have probably been excluded from that habitat (Fig. 1).

4. Flow rate

A clear reduction in flow rate downstream, with a concurrent increase in sediment and silt, as well as an increase in algal growth downstream was found [18]. In general, most studies have found a positive correlation between discharge and stream drift [73, 74, 75, 76, 77, and 78]. Australian rivers suffer mainly from reduced flows resulting from abstraction, alterations in flood frequency, duration and extent, and seasonal reversal of flows as a result of water being stored in dams in the wet season and released for irrigation in the dry season [79]. In a detailed analysis of flow data from rivers in southeastern Australia, it was found that regulated rivers experienced a loss of short-term variation and an increase in predictability of flows. In addition, drought or dry phases have been reduced as a consequence of flow releases during the dry season. A recent review on the consequences of altered flow regimes for aquatic biodiversity suggest that four important principles link hydrology and aquatic biodiversity and can be used to illustrate the consequent impacts of altered flow regimes (Fig. 2) [42]. These principles are:

1. Flow is a major determinant of physical habitat in streams, which in turn is a major determinant of biotic composition.
2. Aquatic species have evolved life history strategies primarily in direct response to their natural flow regimes.
3. Maintenance of natural patterns of longitudinal and lateral connectivity is essential to the viability of populations of many riverine species.
4. The invasion and success of exotic and introduced species in rivers is facilitated by the alteration of flow regimes [42].

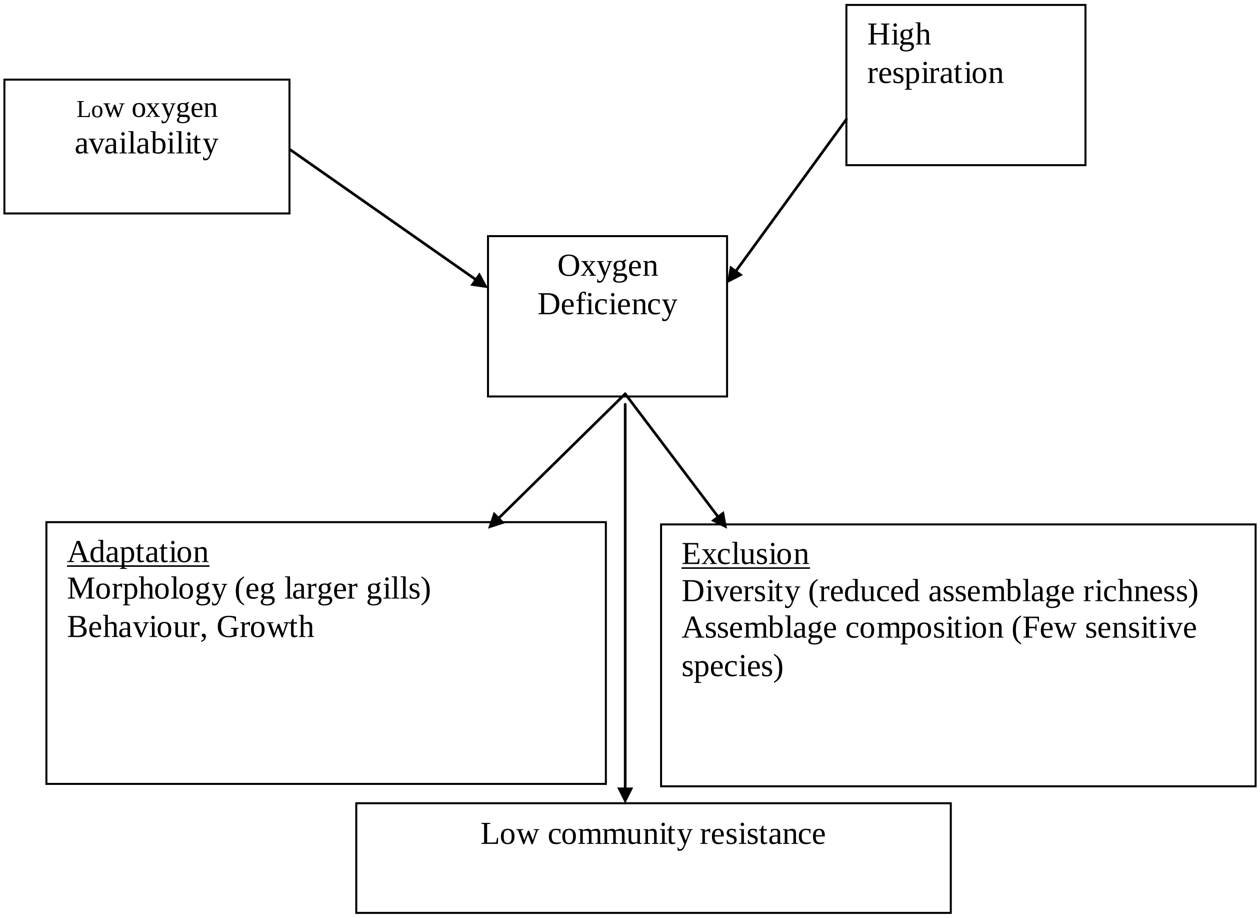

Figure 1: Effect of oxygen deficiency [Jacobsen et al. 2003]

Alteration of community composition was the most common response of macro- and microinvertebrates to modification of flow regimes [55, 80, 81, 82, 83, 84, 85, 86]. However, increases and decreases in secondary productivity [56, 80, 82, 83] and decreases in richness of invertebrate taxa [83, 84, 87] were also noted. Where flow has been reduced, the floodplain mussel of south-eastern Australia has extended its range to the detriment of the river mussel which is adapted to fast flowing water by its large muscular foot and small streamlined shell [88].

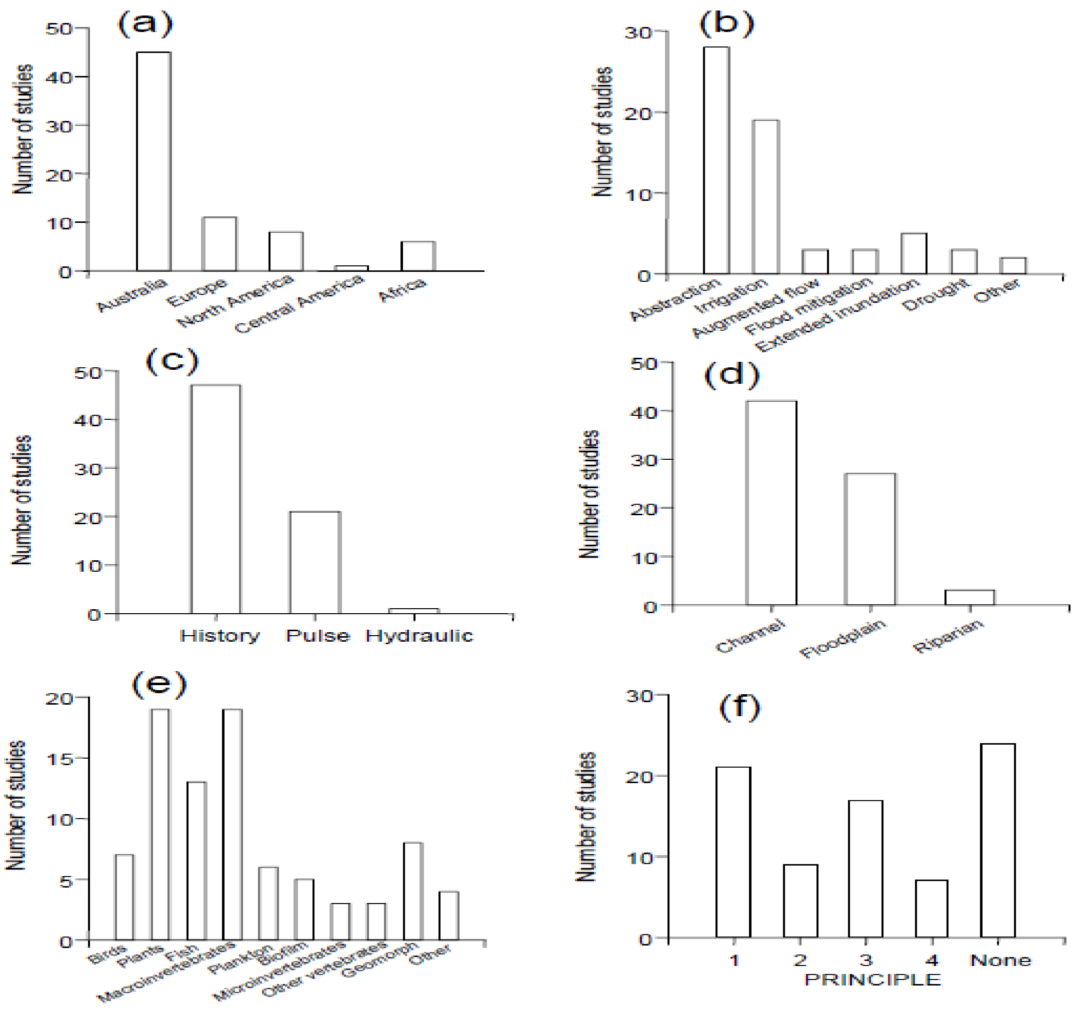

Figure 2. The number of studies included in literature review that were conducted for (a) different geographical locations; (b) type of flow modification; (c) temporal scale of flow modification (d) riverine habitats; (e) taxa studied; (f) principles from Bunn and Arthington 2002 [Lloyd. et al. 2003].

CONCLUSION

This review highlights very strong evidence for ecological changes with reference to macro-invertebrates in response to flow modification. It is apparent that these studies have the necessary quantifiable information on hydrological change and ecological response but do not have in-depth data regarding physiological changes in macro-invertebrates species especially in Asian region. Obtaining and analyzing the data from this research point of view would be rewarding.

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