SYMPOSIUM ON THE ROLE OF DROUGHT IN AQUATIC ECOSYSTEMS

Albury Convention and Performing Arts Centre

Albury, NSW, Australia February 12-14 2001

Sponsored by:-

TIMETABLE

Monday 12 February

9.00 – 9.10	Welcome
9.10 – 9.30	Opening Address

Session 1. Defining Drought

9.30 –10.20	Plenary Lecure **Tom McMahon**
10.20-10.50	TEA Break
10.50-11.10	**D. Roshier** "Distinguishing drought from aridity – the case of desert water birds"
11.10 –11.30	**P.S. Lake** "On the perturbation of Drought in flowing Waters"
10.30-10.50	**E.I Meyer**, E. Schellenberg, R. Zah and M. Sommerhauser "A conceptual Framework for the classification of temporary streams"
10.50-12.10	**N.H Euliss,** G. Swanson, J. LaBaugh, R. Nelson, T. Winter and D. Rosenberry "The Wetland Continuum: A conceptual Framework for interpreting biological studies in the prairie pothole region of North America"
12.10-12.30	**K. Roberts**, R. Noris and M. Thoms "Effects of sustained low flow on habitat availability and benthic macroinvertebrates"
12.30-12.50	**D.B Moffatt** "Quantifying hydrologic drought in the Condamine- Balone River system"
12.50-14.00	LUNCH

Session 2. Drivers of Drought

14.00-14.50	Plenary Lecture **Bryson Bates**
14.50-15.10	**A.P Kershaw**, P. Moss and S. van der Kaars. "Long term climatic variability in the Australian region"
15.10-15.40	TEA

Session 3. The Effects of Drought on Aquatic Biogeochemistry

15.40-16.30	Plenary Lecture **Cliff Dahm**
16.30 – 16.50	**D. S. Baldwin** and A. Mitchell "The role of drying and re-wetting on sediment-nutrient dynamics"
16.50-17.10	**P. Davies**, S. Bunn, and T. Mosisch "Carbon metabolism of a dryland river - wet and dry comparisons"
17.10-17.30	**R. Oliver** and I. Lawrence "Impact of drought on reservoir water quality and ecology"

Tuesday 13 February

Session 4. Drought and Productivity

9.30-10.20	Plenary Lecture **Emily Stanley**
10.20-11.00	TEA
11.00-11.20	**S. Bunn**, P. Davies, F. Balcombe, S. Balcombe and M. Winning "Importance of aquatic production to the food web of a dryland river: flood and famine"
11.20-11.40	**J. Roberts** "Understanding the role of drought in plant communities of wetlands and floodplains"
11.40- 12.00	**S. Capon**, "Drying Times: The importance of variable flow regimes to plant communities in arid floodplains"
12.00-12.20	**K.S Jeong**, GJ Joo and F. Recknagel. "The impact of drought on the phytoplankton dynamics of the lower Nakdong river: Modelling cyanobacterial and diatom blooms"
12.20-13.00	LUNCH

Session 5. Drought and Fish Population Dynamics

13.00-13.50	Pleanry Lecture, **Bill Matthews**
13.50- 14.10	**R. Kobza** and J. Trexler "The role of seasonal hydrology in the dynamics of fish communities inhabiting karstic wetlands of the Florida Everglades"
14.10-14.30	**E. Marsh-Matthews** and W. Matthews "Response of a South Okalahoma (USA) stream fish community to simulated drought"
14.30-14.50	**M.R Douglas**, P. Brunner and M.E. Douglas "Post-Pleistocene drought in western North America: Did it force Colarado River Flannelmouth (*Catostomus latipinnis*) through a genetic bottleneck"
14.50-15.10	**M.E Douglas** and M. R. Douglas "Post-Pleistocene drought at the community level: Molecular evidence from endemic Colorado River fishes in western North America"
15.10-15.40	TEA
15.40-16.00	**T. Baker** and C. Jennings "Striped Bass Survival in Lake Blackshear, Georgia during drought conditions: implications for restoration efforts in Gulf Coast drainages"
16.00-16.20	**M. Kennard**, B. Pusey, A. Arthington "Temporal Variability in discharge and physical habitat influences fish assemblages in the Mary River, South-East Queensland"
16.20-16.40	**D. Magoulick** "Stream drying and fish assemblages in the Ozark Mountains: spatial-temporal variation and source-sink dynamics"
16.40-17.00	**G. Wilde**, B. Durham, K. Ostrand and T. Bonner "Drought effects on West Texas USA, prairie stream fish assemblages"
17.10-18.30	Poster Session

Wednesday 14 February

Session 6. Drought in Specific Environments

8.50-9.30	Plenary Lecture **Andrew Boulton**
9.30-9.50	**R. Cashner**, M. O'Connell, J. Humphries and M. Poirrier "Impact of a prolonged period of low rainfall on the aquatic community in the lake Pontchartrain Estuary, Louisiana, USA"
9.50-10.10	**K. Matthews** and K Pope "Drought in high elevation aquatic ecosystems"
10.10-10.30	**N. McMaster** and D. Schindler "Effects of drought on emerging insects in alpine ponds in Banff National Park, Canada"
10.30-11.00	TEA
11.00-11.20	**A. Covich** "Effects of prolonged drought on rain forest streams, Luquillo Experimental Forest, Puerto Rico"
11.20-11.40	**M. Douglas** and S. Lake "Seasonal drought as a determinant of macroinvertebrate communities in tropical streams."
11.40-12.00	**M. Finn**, A. Boulton and B. Chessman "Ecological responses to artificial droughts in unregulated streams"
12.00-12.20	**K. Jenkins**, A. Boulton and B. Gawne "Defining drought for wetland invertebrates in a dryland river: ecological oxymoron or non-existent state?"
12.20-12.40	**B. Gawne** and I. Ellis "Why are ephemeral wetlands different?"
12.40-13.00	**A. Dell**, R. Alford and R. Pearson "Broadening the perspective: intermittent pools are more than just an intermittent aquatic habitat"
13.00-14.00	LUNCH
14.00-14.20	**M. Ilheu**, P. Guilherme, J. Bernardo and M. Morais "Fish mortality in the summer pools of a temporary Mediterranean stream"
14.20-14.40	**L. Serrano**, K. Fahd and J. Toja "The influence of scale on the study of zooplankton in temporary ponds"
14.40-15.00	**M. Brock**, D. Nielsen, R. Sheil, J. Green and J. Langley "Drought and aquatic community resilience: The role of eggs and seeds in sediments of temporary wetlands"
15.00-15.20	**J. Porter** "The influence of water regimes and salinity on macrophyte seed banks in arid zone wetlands"
15.20-15.40	**M. Salequzzaamn**, A. Miah, N. Huda and S. Sannamat "Anthropogenic impacts and sustainability of wetlands: Case Study Chanda Beel, Bangladesh"
15.40 -	Close and TEA

Session 1 – Defining Drought

Plenary Lecture

DROUGHT AND ANTI-DROUGHT

T. A. McMahon[1] and B. L. Finlayson[2]

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Centre for Environmental Applied Hydrology
[1]Department of Civil and Environmental Engineering, The University of Melbourne
[2]School of Anthropology, Geography and Environmental Studies, The University of Melbourne

Droughts cannot be defined other than by culturally driven judgements about the extent and nature of impact. We do not attempt to define the term but rather describe the nature of low flows in rivers. The paper begins with a discussion of the hydrological processes responsible for low flows. The characteristics of low flows in Australian rivers are described at the monthly and annual time scale using typical examples from each of the seven flow regime zones in Australia as well as an arid zone stream. Four types of low flow sequences are represented in the data for these stations and we also describe lengths of runs of low flows and trends and quasi-cycles in the records.

Two examples are used to illustrate the effects of river regulation on low flows. It is our contention that the indigenous biota of Australian rivers are adapted to the naturally occurring low flow conditions and that while there is considerable scientific interest in the effects of climate change on stream ecology, such studies have little practical relevance. The changes brought about by the regulation of rivers are much more rapid and dramatic than those which might occur due to climate change and it is possible to develop management procedures to mitigate them. In regulated rivers, the real problem may be 'anti-droughts' – the removal of significant natural low flow events from the flow pattern.

Session 1 – Defining Drought

DISTINGUISHING DROUGHT FROM ARIDITY – THE CASE OF DESERT WATERBIRDS

David Roshier

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An understanding of the impacts of drought requires the definition of a spatial, temporal and biotic context to have meaning. Australia's arid inland supports an abundant and diverse aquatic fauna. Long periods without rain are the norm in these desert ecosystems. Therefore defining drought as "an unusually long period without rain" highlights the need to define "unusual". Weather patterns in desert ecosystems are highly variable in time and space and consequently so are the distribution of biotic resources. It would be difficult to define any one weather event as unusual and a decline in biotic resources at one scale will affect some organisms and not others. I illustrate these concepts using Australian waterbirds as an example. Most wetlands in arid Australia are temporary or semi-permanent yet they support internationally significant waterbird populations. For mobile waterbirds capable of interacting with wetland resources at large spatial scales, some of the most arid parts of Australia in terms of rainfall occasionally provide the extensive areas of wetland. Therefore, wetland habitat availability is a time by space interaction that is species specific. For mobile species of waterbird the Lake Eyre Basin has extensive areas of wetland habitat most of the time, although individual wetlands may be used only once in lifetime. Furthermore, the scale at which particular species interact with the landscape may also vary with time. In arid ecosystems this is probably the most significant impact of 'drought'. Therefore, the impacts of drought, water extraction or other impacts on the water regime of Australia's inland rivers cannot be determined unless the spatial, temporal and biotic context of what has been observed has been explicitly stated.

Session 1 – Defining Drought

ON THE PERTURBATION OF DROUGHT IN FLOWING WATERS.

P.S.Lake,

CRC for Freshwater Ecology and Department of Biological Sciences, Monash University, Clayton, Victoria 3168, Australia.

Drought as a perturbation in streams consists of an increasing ramp disturbance that induces a variety of dynamic biotic responses. Droughts may be predictable and short-term seasonal events as occurs, for example, in streams of the Wet Tropics and mediterranean-climate regions. However, the more unpredictable, extended droughts, that arise usually through the failure of seasonal rains, are "creeping disasters" inflicting both ecological and economic damage. Droughts in streams arise through progressive deficits in rainfall, runoff, and soil moisture. Whereas floods generate increased hydrological connectivity in rivers, droughts damage stream ecosystems by reducing, if not, fragmenting hydrological connectivity.

Reduction in flow leads to reductions in stream transport, water quality and habitat availability and condition. The effects of drought and their severity may differ between temporary and normally perennial streams. In a drought, depending on the channel configuration and the sources of surface flow that persist, different patterns of fragmentation arise. As habitat diminishes, biotic interactions within a stream, such as predation, may intensify. Further, predation and scavenging by terrestrial animals on the aquatic biota may increase, especially in the latter stages of drying. Stream biota possess an array of mechanisms of refugium use to deal with drought and these vary with locality. In general, recovery from seasonal drought in temporary streams is both rapid and predictable, whereas in perennial streams recovery from drought may be slow and unpredictable in species composition. Human pressures on streams can reduce flow and exacerbate and extend droughts. Given human pressures and the predicted increase in extreme hydrological events with global warming, it is essential that a concerted effort be made to understand the ecology of droughts in freshwater ecosystems.

Session 1 – Defining Drought

A CONCEPTUAL FRAMEWORK FOR THE CLASSIFICATION OF TEMPORARY STREAMS.

Meyer, E.I[1], Schellenberg, E.T.[1], Zah, R.[2], and Sommerhäuser, M.[3]

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[3] *University of Essen, Institute of Ecology, Department of Hydrobiology, D-45117 Essen*

A precondition for generalising ecological results from streams affected by drying is a differentiated analysis of observed phenomena across a broad scale of running waters. On a large scale natural environmental settings are the major determinants of flow regimes. These, in turn, form the constraints for many abiotic and biotic ecosystem characteristics including, among others, biological processes and adaptation strategies of organisms. For the among-stream comparison of drought impacts a widely applicable typology of low flow situations and drought events is needed.

In this paper we suggest five ecological relevant key parameters for characterising drought events in streams: predicability, frequency, duration, intensity/spatial extent, and cause of drying. Specific settings of these key parameters are combined to define distinct types of temporary streams. On a global scale those are ephemeral streams, estuaries, tropical streams, mediterranean streams, temperate streams, chalk streams, polar streams, regulated rivers/fluctuation, and regulated rivers/low discharge. We emphasise the need of systematic analysis of flow regimes to validate the proposed typology. Whether these basic stream types have to be further refined for the regional scale has to be proved in future.

Session 1 – Defining Drought

THE WETLAND CONTINUUM: A CONCEPTUAL FRAMEWORK FOR INTERPRETING BIOLOGICAL STUDIES IN THE PRAIRIE POTHOLE REGION OF NORTH AMERICA

N.H. Euliss, Jr.[1], G. A. Swanson[2], J.W. LaBaugh[3], R.D. Nelson[4], T.C. Winter[5], and D.O. Rosenberry[5].

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Based on current knowledge of the effects of ground-water flow systems on water permanence and salinity of wetlands, as well as the variable response of ground-water flux to climatic cycles, the interplay of physical variables can be related to biological communities in a meaningful way. The hydrologic continuum of prairie wetlands in space and time provides the necessary framework for integrating predictable and observable biological features of prairie wetlands in the same sense as proposed for lotic systems by Vannote et al. (1980) with the River Continuum Concept. In contrast to the river continuum, however, the continuum for prairie wetlands reflects strong gradients in both the spatial hydrologeologic characteristics among hydrologically interconnected wetlands as well as in temporal events that modify the biological productivity of individual wetlands as they cycle between wet and dry periods. Ecosystem studies at the Cottonwood Lake area over the past 30 years illustrate how spatial and temporal hydrologic continua affects the biota of prairie pothole wetlands throughout wet and dry cycles. Data from the site were used to develop a conceptual model for the wetland continuum proposed here to facilitate valid comparisons among studies, thereby advancing the science and management of prairie pothole wetlands.

Session 1 – Defining Drought

EFFECTS OF SUSTAINED LOW FLOW ON HABITAT AVAILABILITY AND BENTHIC MACROINVERTEBRATES.

Kate L. Roberts, Richard H. Norris and Martin C. Thoms.

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Natural stresses such as drought can cause changes in macroinvertebrate community composition over time. This study examined the relationship between low flows, habitat and the macroinvertebrate community composition. Low flow was defined as those flows less than or equal to the 90th percentile, on the annual flow duration curve. During the study low flow was experienced between November 1997 and June 1998, in the upper Murrumbidgee catchment in the Australian Capital Territory. This flow threshold was not only used to define low flows but also to test for changes in macroinvertebrate habitat (channel morphology) and macroinvertebrate assemblages. Results indicate that although low flows reduced the available habitat for macroinvertebrates, however, macroinvertebrate abundance per unit area and community composition showed no significant response to the effects of low flows. Also, the AUSRIVAS predictive models detected little change in the biological condition of macroinvertebrate communities under low flow conditions. The threshold value used to determine drought was useful in determining habitat change, but was not related to change in the macroinvertebrate community. The effects of low flow on macroinvertebrate habitat depended largely on river channel characteristics, with more marked effects observed in complex channels because of habitat fragmentation.

Session 1 – Defining Drought

QUANTIFYING HYDROLOGIC DROUGHT IN THE CONDAMINE-BALONNE RIVER SYSTEM (QUEENSLAND, AUSTRALIA), USING THE STANDARDISED PRECIPITATION INDEX AS A TOOL FOR EXAMINING THE HYDROLOGIC IMPACTS OF WATER RESOURCE DEVELOPMENT AND DETERMINING ENVIRONMENTAL FLOWS.

D.B. Moffatt

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Twelve-month Standardised Precipitation Index (SPI) values were calculated for 70 year time-series of simulated flow data output from a hydrologic model of the Condamine-Balonne river system. The hydrologic model used enabled simulation of natural flow, and flow under a variety of water resource development scenarios, allowing drought to be defined under simulated natural conditions, and the resulting definition applied to data output from the water resource development scenarios being assessed. Flow within the Condamine-Balonne is seasonal and episodic, and calculated hydrologic drought statistics were strongly correlated with the duration of "no flow". However, this is unlikely to be the case in other river systems where flow is more perennial. Under present level of water resource development, the magnitude, duration and severity of hydrologic drought at some locations along the Condamine-Balonne river system appears to have increased up to about six times that under natural conditions. This is likely to have had major ecological impacts upon the river system, and additional protection of flow during extended dry periods is required to minimise these impacts.

Session 2 –Drivers of Drought

Plenary Lecture

WHAT DRIVES DROUGHT?

Bryson C. Bates

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Our understanding of climate variability has made enormous strides over the last 20 years. Climate phenomena are highly connected across a large range of time scales and latitudes, and vary at every frequency (seasonal to millennial, and beyond). They are often associated with changes in atmospheric circulation that encompass areas far larger than the affected region. Instrumental and palaeoclimatic records indicate that a shift between dramatically different climate states can occur in a matter of years to decades. Thus an understanding of the drivers of drought requires knowledge of the global climatic system.

The presentation provides a non-technical overview of the global climate system, the role of ocean–atmosphere interactions in generating drought, and results from a study of the 25-year hydrological drought in south-western Australia. The global climiate system represents the response of the coupled ocean–atmosphere system to solar radiation, the earth's rotation and orbit, and the spatial distribution of oceans and continents. Australia is an island continent lying in the Southern Hemisphere, 81% of which is covered by ocean waters. Thus variations in Australia's climate stem from changes in the Pacific, Indian and Southern Oceans. The relative effects of each ocean wax and wane over time, adding to and subtracting from the other. El Niño episodes often lead to drought over northern and eastern Australia, and the Indian Ocean can temper or reinforce their impact. Recent work suggests that the influence of the Antarctic Circumpolar Wave on rainfall over southern Australia may be stronger than that of El Niño. Results from the case study suggest that the drying trend over south-western Australia is due to atmospheric circulation changes during the mid 1970s and prior to 1958. The underlying causes appear to be changes in the behaviour of El Niño and the weather systems generated by the Southern Ocean.

Session 2 –Drivers of Drought

LONG TERM CLIMATIC VARIABILITY IN THE AUSTRALIAN REGION

A.P. Kershaw, P.T. Moss and S. van der Kaars

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Throughout the world, extant biotas have had to survive and adapt to patterns of precipitation and hydrological change related to extreme glacial-interglacial cyclicity over the last million years or so. In the Australian region, there is increasing evidence, from climate proxies preserved in lake, river and marine sediments, of a superimposed drying trend with enhanced climatic variability over the last few hundred thousand years. It is postulated that the basic cause of this climatic alteration was the development of the West Pacific Warm Pool (WPWP) as a result of oceanic circulation responses to Australia's continued movement northwards into the south-east Asian region and associated changes in land-sea configurations. The existence of the WPWP was an important prerequisite for the development of El Niño-Southern Oscillation (ENSO) variability and hence increased likelihood of droughts. Spectral analysis of one continuous pollen and charcoal record suggests that ENSO activity has a 30,000 year periodicity and that environmental impact was most marked when high ENSO activity coincided with conditions that promoted high burning levels. It is likely that the progressive impact of ENSO-induced burning led to an alteration in vegetation composition and cover which, through interaction with climate, resulted in increased continental drying. Accelerations in rates of environmental change around 35-40,000 and 5000 years BP were most likely the result of the initiation of periods of high ENSO activity coinciding with the early presence of people on the continent and intensification of human impact, respectively. Even in parts of the continent where ENSO is not considered to be a major influence, its affects may have been registered through the interaction between ENSO and other components of the climate system such as the summer monsoon. An appreciation of this strong environmental trend is important to the understanding and management of the particular biota and aquatic systems of Australia.

Session 3 – The Effects of Drought on Aquatic Biogeochemistry

Plenary Lecture

BIOGEOCHEMISTRY OF SURFACE WATERS AND ALLUVIAL GROUND WATERS IN STREAMS DURING DROUGHT

Cliff Dahm

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Drought can be defined as an unusually long period without rain or a protracted period of deficient precipitation. The consequences of drought on the biogeochemistry of aquatic ecosystems have not received much study. For streams, most studies have focused on the transport of solutes such as nitrate after the cessation of drought conditions. The end of drought normally brings a flush of dissolved nutrients and organic carbon into streams. In this presentation, I will focus on the effects of drought on the biogeochemistry of surface waters and alluvial ground waters using limited published studies and data from ongoing research on the hydrogeology, biogeochemistry, and ecology of the surface water and ground water interface of streams in New Mexico, USA.

Hydrologic effects of drought impact interactions between surface waters and ground waters. Lowered water tables in drought years affect upwelling and downwelling zones through the bed of stream channels, producing complex spatial patterns with distinct losing and gaining sections of stream. Groundwater recharge predominates over discharge in most stream segments during drought. Surface water flows are increasingly derived from inputs of deeper regional sources of ground water that are usually low in dissolved organic carbon (DOC) with low to moderate concentrations of dissolved nutrients. Microbial metabolism rates in alluvial ground waters are limited by the availability of labile DOC during drought, and anaerobic or low oxygen conditions become increasingly prevalent in ground waters at interfaces between ground waters and surface waters under drought conditions. Nutrient limited conditions for stream primary producers are more likely to prevail during periods of drought. Spatial patchiness in algal primary production and the structure of the algal community mirror the heterogeneous distribution of sources and sinks of nutrients. Localized zones of groundwater discharge become regions of enhanced primary production and invertebrate grazing due to low concentrations of dissolved nutrients in most surface waters. Improved understanding of the effects of drought on stream biogeochemistry requires an integrated research effort linking hydrogeology, geochemistry, microbial ecology, and aquatic ecology, as all these fields contribute substantively to the biogeochemical response of streams to drought conditions.

Session 3 – The Effects of Drought on Aquatic Biogeochemistry

THE EFFECT OF DRYING AND RE-WETTING ON SEDIMENT NUTRIENT DYNAMICS

D.S. Baldwin and A.M. Mitchell

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In this paper we discuss the effects of drying and subsequent re-wetting on the N and P dynamics in sediments from contrasting sites. When sediments from a relatively new reservoir were allowed to dry out for the first time, the drying event had a profound effect on the mechanisms for P uptake and release. P adsorption was significantly reduced compared to sediments that had remained inundated, while microbially mediated P release from the dried sediment was significantly reduced. This contrasts with the P dynamics from sediments from an old wetland where little difference in the P uptake and release rates were found between desiccated and non-desiccated sediments.

In another study, significant N release was observed from reservoir sediments that had only been dried once were re-inundated. This contrasts with littoral sediments that had been subjected to yearly draw-down for ca. 50 years that showed no net N release.

In both cases it is suggested that repeated wetting and drying cycles select for bacteria which are resistant to desiccation.

Session 3 – The Effects of Drought on Aquatic Biogeochemistry

CARBON METABOLISM OF A DRYLAND RIVER: WET AND DRY COMPARISONS.

Peter M. Davies[1], Stuart E. Bunn[2] and Thorsten D. Mosisch[2].

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[2]Centre for Catchment and In-Stream Research, Griffith University.

Cooper Creek in the Channel Country of western Queensland, like many Australian inland floodplain rivers, is characterised by anastomosing channels that interconnect only during highly episodic flooding. Outside of flooding, the river is restricted to highly turbid permanent waterholes. Despite the turbidity, a productive band of algae and diatoms (predominantly the epipelic blue-green *Schizothrix arenaria*), was restricted to shallow littoral zones. Measurements of carbon metabolism using perspex chambers *in situ* showed rates in this littoral zone were extremely high (~3500mgC$m^{-2}$$day^{-1}$); over two-orders of magnitude greater than the mid-channel benthos. After local rainfall, many isolated claypans on the floodplain quickly turned green; indicating significant algal growth. Subsequent experiments were conducted to simulate the effects of flooding and measure the subsequent productivity of floodplain soils. Dry soils were collected from the floodplain and wetted within swimming pools placed on the edge of Cooper Creek. These soils had rates of gross primary production (GPP), after only five days, of about 800 mgC$m^{-2}$$day^{-1}$. Another experiment where dry floodplain soils were collected and returned to the laboratory showed that only hours after wetting, algal material was evident. *In situ* measurements of chlorophyll fluorescence on these soils indicated significant algal growth on many of these samples after three days. A large flood in March 2000 inundated much of the Cooper Creek floodplain (about 16% of the catchment). During flooding, both the newly-inundated benthos and water column had elevated rates of carbon respiration (R_{24}) with GPP increasing with the period of inundation. When floodwaters started to recede, rates of GPP were over 1300 mgC$m^{-2}$$day^{-1}$ and the system had switched to be a net producer of carbon ($GPP/R_{24}>1$). Scaling up the results for area showed that the amount of aquatic carbon produced by a day of floodplain inundation was equivalent to 82 years of aquatic production during the dry.

Session 3 – The Effects of Drought on Aquatic Biogeochemistry

IMPACT OF DROUGHT ON RESERVOIR WATER QUALITY & ECOLOGY

R.L. Oliver,[1] & A.I Lawrence[2]

CRC for Freshwater Ecology
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[2]University of Canberra, Canberra, ACT, 2601.

Recent bio-geochemical analysis of reservoir water quality processes & ecology has highlighted the significant role of reservoir inflow & drawdown in determining nutrient transfer pathways and algal growth & composition.

While reservoir drawdown of 10% to 30% is typical for annual irrigation water supply abstraction, the scale of drawdown is significantly increased during extended dry periods, with up to 98% drawdown of reservoir full volume.

Analysis of 23 years of inflow, water quality & algal data for Burrinjuck Reservoir was undertaken by the CRCFE & CSIRO as part of the LWRRDC & MDBC National Eutrophication Management Program. The period covered several extended dry periods, including the 1976 to 78, 1980 to 83, 1987/88 & 1994 droughts.

The analysis identified drawdown as one of the major determinants of nutrient pathways & algal growth over these periods. viz: the incorporation of the phosphorus rich anaerobic sediments previously located in bottom waters, into the surface mixed layer, with direct release of sediment SRP to surface waters; and concentration of the deposition of organic material in diminished inlet depositional zones, leading to severe reducing conditions and remobilisation of SRP.

Significant increases in algal biomass, alga TP content, and dominance of Blue-Green alga were observed for Reservoir drawdown conditions.

Management implications include the need to limit the rate of water drawdown and the minimum reservoir level in order to limit the risk of elevated SRP values and blue-green algal blooms in surface waters.

Session 4 – Drought and Productivity

Plenary Lecture

EFFECTS OF DROUGHT ON STREAM ECOSYSTEM METABOLISM

Emily H. Stanley[1], Jeremy B. Jones Jr.[2], and Stuart G. Fisher[3]

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[2]Institute of Arctic Biology, University of Alaska Fairbanks, Fairbanks, AK, 99775 USA
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Extended periods of low or absent precipitation have wide-ranging hydrologic and ecological effects on streams. Changes in ecosystem metabolism both during and after low- or no-flow periods are expected to be pronounced, reflecting a complex interaction between biotic resistance and resilience to low/no flow conditions, and spatial distribution of water during the drought phase. We used a heuristic model to investigate changes in whole-stream production and respiration during and after drought. This approach allows us to consider the influence of duration and spatial extent of no-flow conditions, variation in rates of production during onset of drought conditions, and changes in recovery rates following return of baseflow conditions on whole-system metabolism. Thus, the goal of our modeling exercise was to explore potential scenarios and suggest future research directions rather than provide definitive description of changes in metabolism over a drought cycle.

Effects of drought were quantified as degree of departure of production and respiration from baseflow condition over the period of a year for the entire ecosystem. Recovery following drought was described as a recolonization process, and thus was dependent on distance from a perennial water source. Not surprisingly, spatial and temporal extent of no-flow conditions had a pronounced influence on total ecosystem metabolism during the no-flow phase. The spatial distribution of water during low flow conditions became an important determinant of subsequent recovery; scenarios in which several small hydrologic refuges were distributed along the length of the model system showed higher resilience than scenarios in which a single large refuge persisted during the drought phase. In most cases, periods of declining flow were characterized by an increased dominance of respiration over production. Scenarios not considered were non-linear or novel system changes, such as inputs of riparian leaf litter associated with drought, highlighting important considerations for future research efforts.

Session 4 – Drought and Productivity

IMPORTANCE OF AQUATIC PRODUCTION TO THE FOOD WEB OF A DRYLAND RIVER: FLOOD AND FAMINE

Stuart E. Bunn[1], Peter M. Davies[2], Fiona J. Balcombe[1], Stephen R. Balcombe[1] and Michelle A. Winning[1].

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Many Australian dryland rivers are characterised by extensive floodplains with anastomosing channels and distributaries. The river water is highly turbid and remains so even during the long periods between episodic floods. Given these features, we predicted that riverine food webs would be supported by terrestrial sources derived from floodplain exchange during floods, and from fringing vegetation along the vast network of channels during the dry. We also predicted that aquatic primary production would be limited by turbidity, thus making a minor contribution to the food web. Our work on permanent waterholes in Cooper Creek, western Queensland, has shown that this is not the case. Instead, a highly productive band of algae in the shallow littoral zone of waterholes was found to be the major source of energy driving the aquatic food web, maintaining large populations of snails, crustaceans and fish. A large flood in March 2000 transformed this system into a vast, slow-moving wetland, triggering benthic (and pelagic) algal production across the inundated floodplain. This was accompanied by a proliferation of aquatic invertebrates, especially small crustaceans. Ten species of fish were recorded on the floodplain reaching an average biomass of approximately 1.3 tonnes km^{-2}. The diets of all fish species were dominated by aquatic sources but with a greater range of dietary items than that recorded in the dry. Some of this floodplain production undoubtedly returns to river waterholes as fish biomass once floodwaters recede. However, given the small area of permanent waterholes (3.2 km^2) in this region compared with inundated floodplain (several thousand km^2), much of the aquatic production must either be exported downstream or retained on the floodplain. We suspect that algal production is a major contributor to aquatic and terrestrial food webs at local and even landscape scales.

Session 4 – Drought and Productivity

UNDERSTANDING THE ROLE OF DROUGHT IN PLANT COMMUNITIES OF WETLANDS AND FLOODPLAINS

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Pre-occupation with demonstrating the negative effects of water abstraction and river regulation on plant communities of aquatic systems and of quantifying the water requirements for maintaining riverine floodplains and wetlands has focused attention on management-induced drought. The result is that drought is more often perceived in a negative light, and the view that it is one of two extremes in a natural water regime is rarely articulated. Whereas the importance of floods and flooding is becoming formalised, there is no parallel appreciation that drought might have an ecological role, as evidenced by the general lack of Australian studies on species responses or population and community processes. Conceptual models of plant ecological strategies are one means of exploring the role of drought in structuring wetland communities, and in scoping how this might vary depending on wetland water regime and vegetation type. In addition, the consequences of sequential management few records and studies of drought in natural and modified aquatic systems of eastern Australia suggests that drought is a sensitive phase. Some simple protective measures may be needed under current land management practices.

Session 4 – Drought and Productivity

DRYING TIMES: THE IMPORTANCE OF VARIABLE FLOW REGIMES TO PLANT COMMUNITIES IN ARID FLOODPLAINS

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Floodplain plant communities depend on cycles of wetting and drying. In temperate and tropical regions, where regular and predictable flow regimes are typical, flooding has been found to be the primary factor influencing vegetation composition and structure. Many large floodplains in Australia, however, are located in the arid interior where flow regimes are amongst the most variable in the world. Vegetation in these environments persists through both extended periods of drought and vast floods, which are unpredictable seasonally and annually. This paper describes the effects of highly variable flow regimes on floodplain plant communities in arid Australia. Results will be presented from an ongoing study of the Cooper Creek catchment in south-west Queensland. These results show that the spatial and temporal variability in wetting and drying patterns across the floodplain has a central role in maintaining a dynamic and diverse mosaic of plant associations. The implications of this, including the likely impacts on vegetation of flow regulation, will also be discussed.

Session 4 – Drought and Productivity

THE IMPACT OF DROUGHT ON THE PHYTOPLANKTON DYNAMICS OF THE LOWER NAKDONG RIVER: MODELING CYANOBACTERIAL AND DIATOM BLOOMS

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This study is focused on developing models of predicting cyanobacterial and diatom blooms as well as evaluating the impact of drought on those dynamics. Weekly sampling on limnological parameters were conducted at the lower part of Nakdong River. The Nakdong River is highly regulated, having 4 multipurpose dams and an estuarine barrage along its length. Five years' (1994-1998) measurements exhibited the eutrophic situation of the study site (NO_3^--N, 2.7 mg l^{-1}; NH_4^+-N, 0.6 mg l^{-1}; PO_4^{3-}-P, 34.7 μg l^{-1}; chlorophyll *a*, 50.2 μg l^{-1}). A severe drought was observed in 1994's summer (30-year's mean annual rainfall, 1219 mm; 1994's rainfall, 765 mm). A trained recurrent neural-network model with 4 years' (1995-1998) environmental and limnological data recognised the 1994's dynamics of cyanobacterial groups (*Microcystis* sp., *Anabaena* sp., and *Oscillatoria* sp.) and *Stephanodiscus hantzschii* well. From the sensitivity analyses, rainfall and water temperature affected the annual dynamics of both groups. *Stephanodiscus hantzschii* dynamics were also related to silica availability. Changes in rainfall patterns were important on the timing and magnitude of blooms of both the cyanobacteria and *Stephanodiscus*. This study indicates that the drought during summer can affect not only the proliferation of cyanobacteria but, indirectly, the growth of *Stephanodiscus*..

Session 5 – Drought and Fish Population Dynamics

Plenary Lecture:

EFFECTS OF DROUGHT ON FISH POPULATION AND COMMUNITY DYNAMICS

William J. Matthews and Edie Marsh-Matthews

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We review a wide range of documented or putative effects of drought on fish populations or community dynamics, from mild and transient to major and permanent, and test evidence of effects in our own data sets. North American literature is replete with accounts of drought effects on fish assemblages, such as destruction of local populations or post-drought recovery of fish assemblages. Less well known are (1) cumulative effects of repeated dry periods, (2) effects of drought at the scale of decades to centuries, and (3) consequences to fitness or genetic composition of fishes that do survive dry periods. Dry periods should have a range of immediate to long-term consequences for fishes, with different effects at different stages of drought. Most obvious is outright destruction of individuals in shrinking habitats due to physicochemical stress, competition, predation, disease, or related factors, with interspecific differences in survivorship. Less obvious is reduction in condition, post-drought survivorship, or lifetime reproductive fitness in individuals that do survive. At the scale of one to two decades there is little signal that drought has caused permanent change in populations or assemblages of stream fishes, i.e., that effects of drought may be transitory at the scale of a few years, after reproduction and recolonization of dewatered areas. Samples from Brier Creek, Oklahoma, and other sites in the central United States suggest that native fish assemblages in naturally drought-prone areas may survive long low-water periods (if desiccation is not complete), and that local assemblages within one to a few years after a drought retain little signal of the event. However, most of our examples come from dry-lands streams that have typical late summer dry periods. A very different picture may emerge for drought in typically mesic environments, and fish in unique habitats like springs and spring runs may be vulnerable to drought. Finally, no recent data exist to instruct us as to what to expect if drought is permanent, as could occur in some global warming scenarios. Papers in this session address some of the gaps in knowledge identified above.

Session 5 – Drought and Fish Population Dynamics

THE ROLE OF SEASONAL HYDROLOGY IN THE DYNAMICS OF FISH COMMUNTIES INHABITING KARSTIC WETLANDS OF THE FLORIDA EVERGLADES

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We studied the role of hydrological variation and availability of dry-season refugia in shaping the structure of fish communities in karstic wetlands of the Florida Everglades. The Rocky Glades is a wetland region of the extreme southeastern Everglades that is flooded for less than 6 months in most years. Solution holes serve as refugia for aquatic organisms, especially fishes, during the dry season. Our study addressed the following questions: Do fishes accumulate into predictable assemblages in solution holes during the dry season? Do abiotic characteristics of solution holes such as depth, water quality, or habitat complexity determine the assemblages of fishes that persist there? And, how do biotic interactions, especially predation, influence which species survive the dry season to recolonise the marsh surface when the rainy season arrives? To assess relative abundance of fishes, we sampled solution holes in Everglades National Park between January 1999, and July 2000, with non-destructive activity traps, coupled with mark-release-recapture techniques. We collected over 3,500 fishes in 17 species during the study period. Null model analyses of 1999 wet-season data indicated fish assemblages tended toward non-random groupings within solution holes through time. A predominant pattern in these data was the apparent ability of non-native fishes to dominate communities in refugia that experience longer drought. The influence of community membership and habitat characteristics as structuring forces on these assemblages is currently being explored using multivariate analyses. We will present the results of these findings for both 1999 and 2000 fish communities.

Session 5 – Drought and Fish Population Dynamics

RESPONSE OF A SOUTH OKLAHOMA (USA) STREAM FISH COMMUNITY TO SIMULATED DROUGHT

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To examine proximate responses of stream fishes to simulated drought, replicate assemblages of fishes consisting of the five most common species from Brier Creek , Oklahoma, were established in each of eight mesocosm units. Each unit consisted of three pools connected by riffles. In four units, water level was held constant and flow was maintained by pumps for the duration of the experiment. In the other four units, flow was maintained for 6 days after which water level was reduced to allow only subsurface flow for the subsequent 6 days. On day 12, water level was further reduced and flow stopped so that pools remained isolated for an additional 40 days. Environmental conditions (temperature, oxygen) were monitored over the course of the experiment and invertebrate samples of all pools were taken at the end of the experiment. At the end of the experiment fish were collected from all units and preserved. Individuals were counted, measured, weighed, and dissected to determine food consumption and reproductive condition. Responses of individual fish species to drying conditions varied. Of the five species in each assemblage, two showed significantly lower survivorship in drought treatments, but survivorship for the other three species did not differ between treatments. Overall assemblage structure differed between treatments. For two species, individuals in drought treatments were in worse condition (as assayed by weight-length regression) than those in flowing treatments, but condition did not vary between treatments for the other three species. The time-course of this experiment coincided with an extreme dry period in natural streams in southern Okalahoma. Fishes collected from natural drying pools in Brier Creek were also in poor condition.

Session 5 – Drought and Fish Population Dynamics

POST-PLEISTOCENE DROUGHT IN WESTERN NORTH AMERICA: DID IT FORCE COLORADO RIVER FLANNELMOUTH SUCKER (*CATOSTOMUS LATIPINNIS*) THROUGH A GENETIC BOTTLENECK?

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The Colorado River Basin encompasses five states in western North America and 600,000 km^2. Its endemic mainstem fish community is ancient (i.e., Miocene) but depauperate (two families, five genera, 8 species). Four species are federally endangered, two are 'candidates,' and two are enigmatic. We evaluated one widely distributed candidate (flannelmouth sucker, *Catostomus latipinnis*) for basin-wide genetic and geographic structure. Three fast-evolving mtDNA genes [ND2 (640 bp); ATPase8 (126 bp), and ATPase 6 (530 bp)] were sequenced from 24 populations (10--20 individuals each, 350 total individuals). Only 26 unique haplotypes were found (83% representing one transition in single individuals). AMOVA revealed 75% of observed variation was within populations, 13% among-populations-within-basins, and 15% among basins. Haplotype distribution suggests a recent expansion from the lower into the upper Colorado River basin. Populations in these two regions apparently diverged from one another 3,385-10,923 ybp. The shallow genetic history and recent coalescence of lineages in this study are unusual given the fossil history of the species, our broad geographic sampling, the rapid rate of mtDNA evolution, and the number (and evolutionary rate) of the genes examined. The most parsimonious explanation for these data is a rapid expansion following a recent period of low effective population size. A concomitant and abrupt extinction of 35 North American mammal species also occurred end-of-Pleistocene. While numerous hypotheses are posed, the most realistic implicates vast climatic alteration and habitat destruction. The hypsithermal (an exceedingly warm and dry post-Pleistocene period) swept the North American continent from west to east. Its maximum in the intermontaine west was circa 7,500 ybp. We suggest that intense drought during this period severely impacted not only large mammals, but also fishes. These results have important implications for conservation of endangered and threatened species, particularly those defined from a molecular standpoint as evolutionarily significant units (ESUs).

Session 5 – Drought and Fish Population Dynamics

POST-PLEISTOCENE DROUGHT AT THE COMMUNITY LEVEL: MOLECULAR EVIDENCE FROM ENDEMIC COLORADO RIVER FISHES IN WESTERN NORTH AMERICA

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Large-scale climatic oscillations can extirpate populations and force survivors through genetic bottlenecks. An arid post-Pleistocene hypsithermal, for example, may be responsible for the shallow genetic architecture of an endemic fish in the Colorado River Basin of western North America. This hypothesis was tested herein using molecular data and the comparative method (i.e., by seeking a similar basin-wide effect manifested within the fish community). We evaluated molecular variation of a diminutive cyprinid fish (speckled dace, *Rhinichthys osculus*) differing from the previously discussed flannelmouth sucker (*Catostomus latipinnis*) in phylogenetic and life history. A larger cyprinid with disjunct and patchy distribution (the endangered humpback chub, *Gila cypha*), was also evaluated by contrasting populations from ecologically comparable but distant areas (i.e., lower basin Little Colorado River, Grand Canyon, AZ vs upper basin Yampa River, UT). Our results demonstrated low and non-significant levels of divergence amongst populations (0.002-0.125%), thus rejecting hypotheses that molecular variability among these fishes stemmed either from phylogenetic and life history differences, or from anthropogenic effects. Results also suggest upper- and lower-basin communities last shared common ancestors 3,300-9,615 ybp, and juxtapose well with a post-Pleistocene drought scenario. We determined magnitude of the genetic bottleneck by deriving effective population sizes (N_es) for both sucker and chub in the Little Colorado River. We used a coalescent approach coupled with a five-year open-population estimator (=N_c) and a single 1,640 bp sequence representing three combined mtDNA regions (ND2, ATPase 6/8, and D-loop). From the literature, N_e/N_c=0.10--0.11, whereas for sucker and chub respectively it was 0.068 and 0.046 (=35% and 56% reductions), thus implicating a rather large bottleneck. Clearly, drought events over evolutionary time have had enormous impacts on fishes that still reverberate today. Interestingly, these events are not considered in the adaptive management of western North American threatened and endangered species.

Session 5 – Drought and Fish Population Dynamics

STRIPED BASS SURVIVAL IN LAKE BLACKSHEAR, GEORGIA DURING DROUGHT CONDITIONS: IMPLICATIONS FOR RESTORATION EFFORTS IN GULF COAST DRAINAGES.

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Endemic striped bass *Morone saxatilis* populations in Gulf coast rivers (southeastern USA) have declined dramatically since the 1940's. These declines resulted from anthropogenic activities that limited access to historical spawning areas and adversely affected cool-water springs. Cool-water springs in rivers and reservoirs provide important thermal refuge for striped bass > 5 kg, which generally cannot survive summer water temperatures >25 ^{O}C. Efforts to restore Gulf-strain striped bass populations to self-sustaining levels have been under way since 1950's and continue to the present. In 1999, 27 adult, Gulf-strain striped bass were fitted with radio transmitters and released in Lake Blackshear, Georgia. Data on their survival, habitat use, and movement patterns were used to assess the potential long-term survival of fingerling striped bass stocked in this lake since 1996. Overall, only 11% of tagged fish were re-located in cool-water springs, and all radio-tagged striped bass that remained in the lake died during the summer. Drought conditions (based on rainfall) and groundwater withdrawals during the study caused diminished aquifer levels, and some cool-water springs in Lake Blackshear stopped flowing. Lake temperatures > 27 ^{0}C for 13 consecutive weeks, observed fish kills, intermittent spring flows, and widespread mortality of tagged fish suggest that the long-term survival of stocked striped bass in Lake Blackshear probably will be poor. Successful re-introductions of Gulf-strain striped bass to rivers and reservoirs in their historic range will depend on the presence of cool-water springs. The persistence, abundance, and sizes of springs in this region are heavily dependent on the periodicity of droughts and the magnitude of groundwater use. Regional climatological data indicate that droughts occur about every three years. Therefore, better management of groundwater withdrawals during drought periods will become increasingly important to maintain aquifer levels (and cool-water springs) needed for restoring native striped bass to Gulf-coast rivers.

Session 5 – Drought and Fish Population Dynamics

TEMPORAL VARIABILITY IN DISCHARGE AND PHYSICAL HABITAT INFLUENCES FISH ASSEMBLAGES IN THE MARY RIVER, SOUTH-EAST QUEENSLAND

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The flow regime of the Mary River is highly variable in comparison to other Queensland rivers. Low flows are unpredictable in incidence and duration and periods of elevated discharge may occur at any time of year. However, discharge also varies spatially with many major tributaries of the Mary River prone to frequent periods of extended zero flows, whereas others have highly constant baseflows. This temporal and spatial variation in flow regime is likely to influence the availability of aquatic habitat suitable for freshwater fish in the Mary River. In this study we examine the role that temporal variability in river discharge and consequently, variation in aquatic habitat, has on fish assemblages in the Mary River. Fish and habitat data was collected from 30 individual hydraulic units (riffles, runs and pools) sampled on 10 occasions between June 1994 and June 1997. During the sampling period, the catchment experienced an extended dry period in which many tributary streams ceased flowing and some sites became isolated or dried out completely. The sampling period also included several high flow events that resulted in major changes to physical habitat structure at some sites. Temporal variation in fish assemblages as defined by total species richness, total density, total biomass density, and multivariate assemblage structure were often strongly correlated with habitat features operating at both local scales (e.g. water column depth) and landscape scales (tributary flow regime). Results also suggest that fish assemblages in the Mary River are resilient to high discharge events (except when habitat structure is altered). In contrast, extended periods of low flow influence the availability of suitable aquatic habitat for fish and may be an important regulator of assemblage structure, particularly at the local scale.

Session 5 – Drought and Fish Population Dynamics

STREAM DRYING AND FISH ASSEMBLAGES IN THE OZARK MOUNTAINS: SPATIAL-TEMPORAL VARIATION AND SOURCE – SINK DYNAMICS.

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Droughts and summer drying create unusual aquatic habitats in the form of isolated pools in many small streams around the world. I examined whether these pools act as sources or sinks for fish populations and the spatial and temporal variation in fish assemblage structure, their relation to abiotic environmental variables, and associations among species. Fish were sampled from 1995 to 1998 and 2000 from pools of Indian Creek in the Ozark Mountains, Arkansas, U.S.A. Total fish densities were significantly greater in summer than in winter and most significant associations found among fish species-size classes were positive. Redundancy analysis showed significant differences among pools in both fish assemblage structure and physical-chemical variables. However, groupings of pools based on fish assemblage structure were not always well explained by physical-chemical variables measured at the pool scale. Pool depth, habitat heterogeneity, pool size and dissolved oxygen/canopy cover were important local abiotic factors. Large fish total density, large central stoneroller density (≥80mm TL), and small sunfish (<80mm TL) density were positively related to pool depth. Otherwise, there were no consistent relationships between physical-chemical variables and dependent variables (fish density and species richness) within a year or between years for a given dependent variable. In 2000, mark-recapture techniques were used to determine movement of fish among pools before and after pool isolation. In summer, prior to pool isolation, movement of fish between pools was substantial, and included both benthic and limnetic species. Many individuals moved from riffles and runs into isolated pools during stream drying. Isolated pools appear to act as a source of colonisation at the reach scale, but the surrounding dry habitats likely act as a population sink at the stream scale.

Session 5 – Drought and Fish Population Dynamics

DROUGHT EFFECTS ON WEST TEXAS, USA, PRAIRIE STREAM FISH ASSEMBLAGES

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We studied the effects of drought on fish assemblages in two prairie streams, the Canadian and Brazos rivers, Texas, USA. The Canadian River has perennial flows except during periods of extended drought, such as occurred in 1998 and 2000. The Brazos River also is generally perennial, except in headwater regions, which are intermittent in most years. The Canadian River fish assemblage is numerically dominated by four minnows that spawn semi-buoyant pelagic eggs. During drought, reproduction by these minnows is limited by a lack of flow and the relative abundance of these species decreases. In contrast, relative abundance of nest and crevice spawning species increases during drought. In headwater regions of the Brazos River, fish assemblages in isolated pools undergo a fairly predictable change in composition during periods of drought. During the initial stages of drought, fish assemblages are composed of several minnow species, one livebearer, and two cyprinodontids. As drought continues, isolated pools shrink in size and volume, and become increasingly saline. Fish assemblages of these pools become sequentially depauperate as the livebearer and minnows and then cyprinodontids disappear. The pattern of disappearance is consistent with laboratory determined salinity tolerances for dominant species. In both the Canadian and Brazos rivers, prolonged drought alters the composition and structure of stream fish assemblages. Although recovery from drought usually is rapid, with normal assemblage composition commonly observed by the following year, existing and proposed modifications of these rivers may exacerbate drought effects resulting in reduced species diversity.

Session 6 – Drought in Specific Environments

Plenary Lecture

DROUGHT IN SPECIFIC ENVIRONMENTS: PARALLELS AND CONTRASTS

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It is axiomatic that unusually long dry periods (droughts) should adversely affect the biota of aquatic habitats. It is also generally accepted that the effects of drought in ephemeral or temporary waters are less severe than in permanent waters that dry because the biota of temporary waters possess various strategies to survive drying. While we know something of the physiological and behavioural adaptations by some aquatic plants and animals to drying, there are fewer empirical data on the longer-term responses to drought frequency and predicability. As human activities ranging from localised water abstraction and river regulation to global deforestation and climate change alter the frequency, duration, and predicability of drought, we must assess the severity of these changes upon the biota and ecosystem processes of various aquatic habitats.

In this paper, I review the literature on responses by macroinvertebrates to drought in specific environments ranging from ephemeral lakes to permanent rivers, testing the hypothesis that drought in more permanent aquatic habitats has a longer-lasting influence on macroinvertebrate biodiversity and abundance. Macroinvertebrates mediate many ecological processes in permanent and temporary waters, and many have strategies for dealing with drought. Given the increasing demands for surface and groundwater, we need to assess how specific aquatic environments are threatened by increasing duration or frequency of drought in various parts of the world. Are there 'thresholds' of periods of drought that result in marked changes in faunal composition in different aquatic environments? Are certain groups of macroinvertebrates favoured by increasing duration or frequency of drought, and if so, how might these faunal changes influence rates and directions of ecological processes within specific environments? What are the likely effects of increasing duration and frequency of drought upon invertebrates of groundwater dependent ecosystems? Finally, what measures can we take to protect specific environments threatened by anthropogenic drought?

Session 6 – Drought in Specific Environments

IMPACT OF A PROLONGED PERIOD OF LOW RAINFALL ON THE AQUATIC COMMUNITY IN THE LAKE PONTCHARTRAIN ESTUARY, LOUISIANA, USA.

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Lake Pontchartrain is a large (164,000 hectares) estuary that occupies most of southeastern Louisiana, USA. The lake is characterised by its low salinity (typically 1-7 o/oo), relative shallowness (ž < 5 m), and susceptibility to both natural and artificial disturbances. Currently the estuary is subject to the most prolonged period of low rainfall in 20 years. Through September 2000, rainfall was more than 620 mm below the annual average. Reduced freshwater input to Lake Pontchartrain has resulted in a striking increase in salinity (range of salinity = 10–18 o/oo). This impact is reflected in the fish assemblage, invertebrate communities, and vegetation comprising the grass beds. During the summer of 2000, May-Sept., a survey of fishes yielded more than a dozen marine forms that have been absent or only rarely collected in the basin over the past 45 years. The occurrence of these marine species in the typically oligohaline estuary has numerous ecological implications. Also taken in trawls and seines were marine jellyfish and small squid. A brackish water clam, *Rangia cuneata*, is a keystone species in the lake and has just recently returned to high densities with the cessation of shell dredging after decades of decline. Currently, the species is being eliminated from the Lake's eastern sector by high salinity and is decreasing in abundance in the western sector. The submerged aquatic plant *Ruppia maritima* has increased in distribution and abundance beyond historic levels, while another species, *Vallisneria americana*, continues to decline. Comparisons of fish assemblages from years of normal rainfall and those of low rainfall will be made using a database of collections that spans nearly 50 years.

Session 6 – Drought in Specific Environments

DROUGHT IN HIGH ELEVATION AQUATIC ECOSYSTEMS

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High elevation (> 3000m) aquatic ecosystems are well known for their extreme ranges of temperatures and conditions, yet little is known about the role of drought and how it affects the aquatic environment and the associated biota. In high elevation systems, lake and pond water levels are dependent upon snowmelt but levels are maintained and augmented by summer thunderstorms. Our studies of high elevation amphibians demonstrate that frogs require a variety of aquatic habitats including large deep lakes and shallower ponds depending upon their breeding, feeding, or overwintering needs. We have found that frogs are likely more adapted to the extreme winter conditions, and that summer drought can result in low survival if important shallow areas dry up before tadpoles metamorphose or if lower water level at lakes edges result in reduced overwintering sites (some frogs overwinter in nearshore ledges and crevices). Drought conditions during the summer may represent the critical stressful period to high elevation amphibians and reptiles especially those that use shallower or ephemeral water bodies. For example, after a long winter in 1997-1998 with 150% normal snowfall, survival of the mountain yellow-legged frog *Rana muscosa* was high (>80% of tagged individuals were recaptured in the following summer of 1998) in a high elevation basin in the Sierra Nevada, California. In contrast, low summer rainfall and pond water levels were associated with reduced winter habitat and low survival. Moreover, the role of drought and amphibian survival has become increasingly important because widespread non-native fish introductions into the larger, deeper lakes have relegated many amphibians to the shallower and ephemeral habitats more prone to drought impacts. Because many high elevation aquatic ecosystems support amphibians, it will be important to understand the role of drought especially in light of worldwide amphibian declines.

EFFECT OF DROUGHT ON EMERGING INSECTS IN ALPINE PONDS IN BANFF NATIONAL PARK, CANADA

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Investigating the effects of drought on aquatic systems and organisms is increasingly important as climate change increases the frequency of dry years. Small shallow aquatic systems with high surface to volume ratios such as ponds will be extra sensitive to drought, making them unusually vulnerable to climate change. This is especially true for alpine ponds because alpine regions are predicted to have a greater temperature increase than lower elevations. Five alpine ponds in Banff National Park, Canada, were studied from ice-out in June through September for three years to determine the influence of drought on the emerging insect community. We hypothesised that drought would a) increase species richness, abundance, and diversity; b) accelerate development, resulting in earlier peak emergence and shortened emergence event; and c) have greater effect on insect communities in large and deep ponds than in small and shallow ponds. The summer of 1998 was extremely warm and dry. The summer of 1999 was cool and very wet. The summer of 2000 was cool and dry. In all three summers, water level and volume decreased, and water temperature and conductivity increased. Trends were stronger during 1998, the drought year. During that year emerging insect abundance and species richness was lower; timing of insect emergence was much earlier (> month); and the emergence event was shorter than in the other two years. These results appear to depend more on decreased depth and volume then increased temperature. Further analysis will give a clear illustration the effect that drought has on the emerging insect community in these alpine ponds.

Session 6 – Drought in Specific Environments

Effects of Prolonged Drought on Rain Forest Streams, Luquillo Experimental Forest, Puerto Rico

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Some tropical regions such as Puerto Rico are considered "aseasonal" because rainfall occurs every month; other regions have distinct dry seasons. Although these relationships are influenced by El Nino-Southern Oscillation events, Caribbean streams apparently receive only a weak El Nino signal (increased rainfall during May). However, hurricanes greatly alter patterns of rainfall (from August through November). A 10-year record of freshwater shrimp distributions from the Luquillo Experimental Forest is an example of how extreme events result in high variability of litter inputs and benthic responses. Leaf litter inputs are generally continuous throughout the year to a wide range of benthic detritivores in Caribbean streams. However, despite the year-long growing season and warm temperatures, there are periods of food scarcity for detritivores even in permanent streams. Pulsed inputs of litter occur as a result of high winds, intense rains, or severe droughts. The 1994 water year was extremely dry and litter accumulated in riffles and pools, especially from dominant riparian palms. In extremely wet years, storm flows washed litter out of pools and into debris dams or deposited the litter outside the channel. Both vertical and horizontal linkages within drainage networks are altered by extreme events so that benthic species distributions shift in response to changing abiotic or biotic conditions. These feast-or-famine pulsed dynamics apparently alter recruitment into populations of long-lived decapod species. The intensities of drought effects vary depending on local geomorphologic control of groundwater hydrology. Land use also alters drought effects by influencing bank erosion and pool depths. Although, long-term, comparative studies are lacking, drying of tropical rain forest stream biota may be generally intense even if intense droughts are infrequent. Most of these species lack adaptations such as diapause or burrowing deep into groundwaters and are stressed by isolation and reduction of pool habitats.

Session 6 – Drought in Specific Environments

SEASONAL DROUGHT AS A DETERMINANT OF MACROINVERTEBRATE COMMUNITIES IN TROPICAL STREAMS.

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The high temperatures and highly seasonal rainfall of the wet-dry tropics creates a climate that is characterised by predictable seasonal drought. In such climates, seasonally flowing streams are the norm and in northern Australia most streams dry completely for 3-6 months each year. We sampled the macroinvertebrates from two sites in two seasonal streams in Kakadu National Park, NT. Samples were collected at three-weekly intervals over a two-year period. The macroinvertebrate communities of theses streams showed dramatic but predictable seasonal patterns with distinct assemblages occurring repeatedly across years and streams and sites. The faunal dynamics largely reflect the seasonal cycles of physicochemical changes, demonstrating the overwhelming influence of seasonal drought in structuring the faunal communities. Despite biogeographical differences, there were striking similarities between the faunal patterns displayed in these streams and those from intermittent streams of Mediterranean climates.

Session 6 – Drought in Specific Environments

ECOLOGICAL RESPONSES TO ARTIFICIAL DROUGHTS IN UNREGULATED STREAMS

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In unregulated streams, water extractions during the dry season create unnaturally long dry periods of 'artificial drought'. Such extractions increase the duration of droughts, the frequency and predicability of their occurrence, and the rapidity with which draw down occurs. Such artificially enhanced drought conditions are hypothesised to have long and short-term effects on aquatic biota and in-stream ecological processes (such as organic matter cycling).

During droughts, critical habitats such as aquatic vegetation, snags and riffles are exposed, often progressively. Ecological responses to drying are likely to be most extreme at thresholds when these critical habitats are lost, potentially creating a "stepped" ecological response to draw down that may be used to define limits of extractive use. Also, as critical habitats are exposed more often and for longer periods of time, cumulative and long-term changes in faunal composition, allochthonous material transport, and other ecological processes may be observed. Such changes may not be readily reversible.

We compared two stream systems in northern NSW, the Wilson River and the Forbes River, with different levels of water extraction to assess ecological changes occurring during extractive use. Water users along the Wilson River used 90% of the 80th percentile monthly flows during 1994-95, while the Forbes River had only 2% of these flows extracted over the same period. Ecological processes were measured in conjunction with physico-chemical and habitat variables to establish relationships between readily measured physico-chemical variables and specific ecological responses to drying. Ultimately, it is hoped that mapping changes in ecological processes will allow daily flow classes and limits of extraction to be set using a protocol based on rapidly measurable physico-chemical variables as indicators of ecological responses. Presently, extraction limits are determined arbitrarily, and the potential for irreversible ecological damage through sustained artificial drought is unknown.

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DEFINING DROUGHT FOR WETLAND INVERTEBRATES IN A DRYLAND RIVER: ECOLOGICAL OXYMORON OR NONEXISTENT STATE?

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Drought is an unusually long period without rain, where the anthropocentric definition of unusually long varies among climatic regions, but typically relates to a stressed ability to grow food. Declaring drought on the basis of diminished agricultural capacity in semi-arid and arid climates is simplistic and ignores the extreme variability in rainfall patterns. Identifying drought for wetland organisms adapted to dryland climates is complex as their strategies are cued to rainfall and flooding that is sporadic in time and space with extreme variability over a range of time scales (ie. 10s to 100s to 1000s of years). For example, rainfall and flooding on the lower reaches of the Darling River in Australia occurred in four distinct clusters in the last 100 years, with significant floods only in 1890, 1956, 1976 and 1990. Was the dry period for the first half of last century an unusually long period to a wetland invertebrate resting egg? We investigated the influence of time since flooding (1 to 6 years vs. 20 years) on the 'egg bank' of wetland invertebrates. In laboratory microcosms, invertebrate emergence was lowest from wetland sediments last flooded 20 years earlier. Was this due to 'egg banks' diminishing during dry periods, or is hatching simply delayed following long dry periods? Is there a critical dry period, a drought, at which losses to the egg bank affect recovery of populations following a flood? Answering this question is vital as our results show that river regulation is increasing the length of dry period between floods for lakes on the lower reaches of the Darling River.

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WHY ARE EPHEMERAL WETLANDS DIFFERENT?

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Many Australian wetlands have lost their dry phase due to high summer irrigation flows. This change has had a dramatic impact on the structure and function of affected wetlands. Restoration of a dry phase is proposed as a rehabilitation tool, although this is handicapped by our ignorance of the links between drying and wetland condition. Wetlands that dry may have higher abundances of birds, aquatic macrophytes and invertebrates and may be more productive. There are three potential hypotheses to explain these observations. 1) Wetland production is stimulated by nutrients released from dried sediments. 2) Drying changes the food web such that a greater proportion of the available organic matter is consumed by higher trophic levels, and 3) that the physical characteristics of ephemeral wetlands provide better habitat for certain groups of organisms. We will report on a mesocosm experiment in which the food web and water regime were manipulated to examine the effects on lake productivity and the zooplankton community. The work reveals that both mechanisms play a role in structuring wetlands.

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Broadening the perspective: intermittent pools are more than just an intermittent aquatic habitat

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Intermittent freshwater pools are natural bodies of water that experience recurring dry phases of varying duration. These systems constitute small, isolated patches of habitat whose fauna undergo repetitive episodes of colonisation, succession and, in many cases, local extinction. The unique characteristics of intermittent pools have caused them to become model study systems for researchers investigating a great variety of ecological paradigms. However, while previous researchers have recognised the ephemeral nature of the community inhabiting intermittent pools, they have ignored the truly cyclic nature of these habitats: while the aquatic phase of intermittent pools, by definition, does not exist permanently, the substratum that it occupies does. Thus, an intermittent pool habitat is not only an aquatic system that periodically dries, but also a terrestrial system that is periodically inundated. The existence of the intermittent terrestrial system is implicit in the existence of the intermittent aquatic system, but almost all previous community-based studies of the ecology of intermittent pool habitats have begun with the filling of the pool and ceased with its disappearance.

The research we discuss here suggests that drying pool beds are invaded by a group of species that are specific to dry intermittent pool beds. We propose these species are adapted to the cyclic nature of the dry phase of intermittent pool beds just as the aquatic fauna are adapted to the intermittent nature of intermittent pools. Current work is investigating hypothesised dependencies among the ecology of different habitat phases within an intermittent pool bed. For example, changes in the duration of the aquatic phase should strongly affect the structure and functioning of the subsequent dry phase community; likewise, changes in the length of the dry phase should affect the ecology of the subsequent aquatic phase.

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FISH MORTALITY IN THE SUMMER POOLS OF A TEMPORARY MEDITERRANEAN STREAM

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The South of Portugal and a large part of the Iberian Peninsula has very hot summers, high insolation and a mean annual precipitation of 560 mm. Most of the rainfall is concentrated from late autumn to early spring. In the summer no surface flow is observed and the streams present long dry reaches with some isolated pools. During this period fish are subject to extreme conditions, particularly in the shallower pools. As they shrank, some pools were closely monitored (24 hour cycles) to determine the environmental changes and the patterns of fish mortality.

Large fish tend to occupy deeper and larger pools located in the higher stream orders that usually persist through the summer except during severe droughts. In these pools, no critical environmental conditions nor fish mortality were noticed. In the smaller, shallower and least persistent pools, fish assemblages are mainly composed by small specimens, mostly YOY. High mortality rates occur mainly in this type of pools, particularly in those with high plankton biomass. Two periods of mortality events were found during the 24 hour cycles: (i) during the day, from 13:00 to 15:00 hr, when extremely high values of dissolved oxygen (20 to 35 mg/l), pH (9 to 11) and temperatures (30-35ºC) occurred, and (ii) during the night, from 23:00 hr on, when dissolved oxygen reach critically low concentrations (approx.1mg/l). All fish species were affected and apparently the YOY cohorts suffered the higher losses.

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THE INFLUENCE OF SCALE ON THE STUDY OF ZOO-PLANKTON IN TEMPORARY PONDS (DOÑANA N.P, SW SPAIN)

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Scale is a critical problem for the assessment of species richness and biodiversity, especially in temporary habitats. How many samplings should include a study that aims to record the aquatic fauna of an ephemeral environment? How extensive should it be (or how representative are those sampled habitats among a whole array of fluctuating environments)? In the Doñana National Park (SW, Spain) wetlands experience periodic cycles of flood and drought. Most of the area is covered by seasonally-flooded marshes on silty deltaic deposits while hundreds of tiny freshwater bodies are scattered on the sand dunes. Over 200 taxa of zooplankton (microcrustaceans and rotifers) have been identified in 70 of these temporary ponds on the eolian sands since they were first sampled in 1959. However, the number of both crustacean and rotifer taxa that has been collected per site is significantly correlated with the number of studies that has been carried out per site ($r=0.918$ and $r=0.880$, respectively). Thus, the higher number of times a site has been sampled, the higher number of taxa identified. Additionally, the zooplankton record is sparse, as only 14 specific publications are available in a time period spanning 39 years (1959-1998). Along this time, numerous man-made changes have impacted the area. This fact adds a further complication to the interpretation of these monitoring studies framed by spatial and temporal constraints.

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DROUGHT AND AQUATIC COMMUNITY RESILIENCE: THE ROLE OF EGGS AND SEEDS IN SEDIMENTS OF TEMPORARY WETLANDS

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Drying at unpredictable intervals is a feature of many temporary wetlands. Duration and frequency of flooding vary naturally within and between wetlands. To persist in such environments aquatic organisms must have mechanisms to cope with dry times as well as wet times. If they can't persist they must reinvade a wetland after each drying event. A long-lived “seed bank” consisting of eggs, seeds and spores is one survival mechanism. Organisms must also cope with unsuccessful wetting events that allow germination and hatching but do not allow the completion of their life cycles and addition of new seeds and eggs to the "seed bank". A seed bank that does not all germinate or hatch in the first wetting event is one mechanism for coping with such events. In this paper we explore whether these communities are resilient to a range of drying and wetting events by exploring the parallels and contrasts between zooplankton egg banks and aquatic plant seed banks from temporary wetlands. Data from experimental hatching of zooplankton communities from wetland sediments with seasonal (each year), intermittent (wet 1year in 3) and episodic (1year in 20) wetting histories are used to explore zooplankton longevity and hatching from the Murray River Floodplain. Data from experimental germination of plants communities from wetlands sediments with seasonal, intermittent and semi permanent (dries one year in 20) wetting from the Northern Tablelands of NSW are used to explore longevity of seeds from "seed banks” of temporary wetland communities under dry conditions and the depletion of seed banks under multiple “unsuccessful” wetting events. Parallels and contrasts between zooplankton and aquatic plants hatching and germinating after various drying events are used to explore questions of community resilience and wetland sustainability. We explore how communities might change depending on length of time since a wetting event and how resilient these communities might be if the pattern of drought events are changed by human intervention.

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THE INFLUENCE OF WATER REGIME AND SALINITY ON MACROPHYTE SEED BANKS IN ARID ZONE WETLANDS

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The boom and bust ecology of arid zone wetlands is well documented for waterbirds, fish and invertebrates, but knowledge of macrophytes in unregulated river systems and their role in ecological processes is relatively poor. Research on macrophytes in arid or semi arid environments has so far focused on regulated river channels with little attention given to unregulated rivers, floodplain wetlands and salt lakes despite evidence of high productivity. Saline wetlands with dense stands of submergent macrophytes can support up to ten times the numbers of waterbirds and invertebrates as comparable freshwater lakes.

This research examined the influence of water regime (flood frequency, depth and duration) and water chemistry on macrophyte seed banks in nine arid zone wetlands. Seed banks are a persistent signature of macrophyte communities and were used to compare wetlands of varying floodplain connectivity, size, water regime and chemistry. Sampling was structured over wetland types (saline, freshwater, temporary and permanent) and spatial scales (sample, site and wetland).

Permanent saline wetlands had higher seed bank densities than other wetland types. Species diversity was negatively correlated with salinity. Six species were abundant in saline wetlands, while a much larger group (28 species) occurred in temporary freshwater wetlands. Species area relationships varied between wetlands of similar water regime and salinity. Three sets of multivariate descriptors (species abundance, environmental variables and spatial data) from each wetland were used to examine similarities and groupings. Diversity and abundance of macrophyte seed banks is strongly influenced by water regime and salinity. There was considerable variation in patterns of abundance within as well as among wetlands.

ANTHROPOGENIC IMPACTS AND SUSTAINABILITY OF WETLANDS : CASE STUDY CHANDA BEEL, BANGLADESH

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Bangladesh has extensive areas of wetlands. These wetland ecosystems are very important to the economy and life of the peoples of Bangladesh whose living conditions inextricably linked to the productivity and sustainability of wetlands. In recent times, the wetlands of Bangladesh are being reduced as a consequence of both human activities and frequent occurrence of drought. As a result, the biodiversity in these ecosystems is declining.. Among the wetlands, Chanda Beel is an important wetland in Gopalgonj district of Bangladesh, with an area of 10,890 hectares. Once Chanda Beel was rich in flora and fauna, but some of these biological resources are already lost and others are going to be threatened, due to human activities of large scale removal of apple snail (*Pila globosa*), overfishing, unplanned development activities, increased siltation, pollution from pesticides and fertilisers; and occurrence of drought in its main body. It is proven that participatory wetland management (PWM) through grassroots participation is the main input for the sustainablity and sustainable management of Chanda Beel. The paper discuss briefly the causes of destruction of wetlands from the anthropogenic point of view, the occurrence of drought and loss of biodiversity, and participatory management practices for the protection of biodiversity and other resources in Chanda Beel. Finally, the paper discusses aspects of policy and planning for the sustainable management of the wetlands in Bangladesh.

POSTER PRESENTATIONS

IMPLICATIONS OF DRING IN THE MICRODISTRIBUTION OF AQUATIC MACROINVERTEBRATES IN A SEMIARID STREAM OF SPAIN (CHÍCAMO STREAM)

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This study was carried out in a 4th order stream located in Murcia (southeast Spain), one of the most arid regions (annual rainfall less than 250 mm) of the Iberian Peninsula. Chícamo stream has a maximum length of 59.4 Km only 22Km flow permanently, it consists of discontinuous segments. We chose a 100m section in the middle-reach of Chícamo stream, where the flow is continuous. The different habitat types we sampled were visually distinct units within the stream, but with an apparent intrinsic physical uniformity. As a descriptors of habitat heterogeneity we used: current velocity, substrate (bedrock, stone, gravel, sand and silt), depth, and the presence and type of primary producer. Samples were collected weekly during the summer of 1999 (from June to September). All the habitat types present each week within the stream reach were cartography "in situ" and subsequently digitized. Three macroinvertebrates samples were collected at each habitat type and oxygen concentration, water temperature, depth, current velocity, salinity and conductivity were also measured. The aim of this study was to answer the following questions: (1) Are the habitats we defined really different structural units? (2) Are they spatially and temporally stable units or do they change during the summer?; (3) What are the main structuring habitat parameter/s for the fauna? (4) Could we define a particular species assemblages associated with each habitat type or are they similar to one another? (5) How do the fragmentation and water loss of the ecosystem affect the distribution and biomass of the macroinvertebrate assemblages? A total of 27 species of aquatic invertebrates (Dipterans were not determined at specie level) were found during the summer of 1999. Faunal data showed that a relationship exist between species and habitats, mainly related to depth, current velocity and the existence of vegetation.

PHYSIOLOGICAL REFUGIA: INTRODUCED PREDATORS AND PREY FISH COMMUNITIES.

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Hypoxic conditions occur within many aquatic systems. In systems with distinct dry/wet seasons, hypoxic conditions commonly occur during hot dry summers where species not well adapted to such physiological stress are unable to survive the harsh environmental conditions. Fish species utilise various adaptations to maintain effective populations under these conditions. Species which persist in these habitats are often well adapted to breathing air, surface water (Aquatic Surface Respiration), or the utilisation of physiological adaptations such as increased gill surface area or metabolic regulation. Large predators such as perch or trout are often less well adapted to hypoxic conditions than their smaller prey species.

This poster reviews three field distribution and physiological studies to demonstrate the importance of physiological refugia in mediating interactions between introduced and native species, in particular the effect of large introduced predators on prey communities. In the Lerdederg River, an intermittent stream in Southern Victoria, Summer conditions mediate the relative ranges of native Galaxias and the introduced predator *Salmo Trutta*. The introduction of the large predatory Nile perch (*Lates niloticus*) has coincided with the decline or disappearance of hundreds of indigenous fishes. Hypoxic wetlands however have provided structural and low oxygen refugia for prey species from predation by the less tolerant Nile perch. On the floodplain of the Ovens River in North East Victoria, hypoxic billabongs serve as refuges from the less tolerant introduced predator *Perca fluviatilis* (redfin/European perch) for a variety of native and introduced, small fish.

These studies suggest that physiological refugia may be important in modulating the impact of introduced species on indigenous fish communities and highlight the need to evaluate relative tolerance of native and introduced fishes to environmental stressors.

ECOLOGICAL EFFECTS OF DROUGHT IN CANTERBURY, NZ

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The Canterbury region of New Zealand experienced two of its worst droughts during an El Nino event over the 1997-98 and 1998-99 summers. The droughts resulted in low groundwater levels in parts of the region, which in turn resulted in low or zero flows in spring-fed stream and rivers. Flows were also low in foothill rivers fed by coastal rainfall. Some of these experienced 70-year low flows.

The low flows in the streams and foothill-sourced rivers had, in many cases, profound effects on the fishery, water quality, recreational, and wildlife values of those rivers.

This paper describes some of those impacts. The impacts included trout and salmon kills, strandings and a requirement for salvage, caused by a lack of water, elevated water temperatures, or deoxygenation. There were also deaths of native fishes including bullies, galaxiids, flounder, mullet and eels. Salmon and inanga were sometimes unable to migrate to or from the sea because river mouths were closed. Compared with previous years, there was a constriction in habitat for waterfowl and a probable reduction of reproductive success for ducks and quail, because of a lack of suitable water for breeding or drinking. There were also reduced opportunities for angling and gamebird hunting. This resulted in a flow-on economic loss caused by a reduction in revenue from gamebird hunting licences. Unsightly or toxic algal blooms and disagreeable odours also occurred. In at least two cases, the algal blooms were associated with fish kills.

However, these observations are probably only examples of the wider scale, more readily-observed impacts of the 1997-98 and 1998-99 droughts on the east coast of New Zealand.

DIVERSITY, STABILITY AND REPRODUCTIVE ACTIVITY OF A FISH ASSENBLAGE IN A PERMANENT PLUVIAL POOL OF A BRAZILIAN SEMIARID STREAM.

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Dry periods are recurrent events in Brazilian semiarid region. Streams have a great number of ephemeral and perennial pools that are spread over these systems during the dry season. This work aims to analyse the diversity, stability and reproduction of a fish assemblage in a permanent pool of an ephemeral stream from the Brazilian semiarid region. Twenty-six collections were made and 2196 individuals were sampled during different hydrological phases (wet and dry) of two annual cycles (1996-1997). Diversity was analysed by means of Simpson's Diversity Index (S) and the variation in number of species (richness R). The stability of the community was evaluated through the variation in abundance, measured by the Kendall's W. Gonadossomatic Relation was used to measure reproductive activity of fish. Diversity of fishes was low (S = 0.650 and R = 7 species) and dry periods were less diversified than flooded and after-flood ones. Community was considered more stable and less diversified during the first hydrological cycle studied (W = 0.888 $p < 0.001$; S = 0.583), when drought was less intensive (wet period from February to May / 1996) with weak and more frequent floods during the wet season. During the second hydrological cycle studied, community was less stable and more diversified (W = 0.584 $p < 0.001$; S = 0.723). During this year drought was more intensive (wet period only in March / 1997) and floods were stronger but less frequent. Reproductive activity was considered incipient during the period studied. Despite the harsh conditions found in permanent and ephemeral pools, these habitats are valuable places to the Brazilian semiarid region, because in pools fish can became stocked and persist through out dry periods.

TEMPORARY STREAM TYPES OF A KARSTIC ENVIRONMENT

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Temporary streams are a characteristic feature of karstified limestone terrains. Due to the various geohydrological conditions, many karst streams have different, partly extreme discharge regimes. Therefore it seemed to be difficult to apply low flow typology to temporary karst streams. In recent studies with regional typological aspects karst streams are not considered or they are just characterised as ephemeral or episodic streams though there exists a high variety of stream types.
In this paper we attempt to classify hydrologically the different karst streams of the Paderborner Hochflaeche, a karstified area of about 350 km^2 in northwest Germany. Based on several recent and current studies we use these characteristic parameters of drought: spatial extension, duration, intensity, frequency and predictability.
Furthermore, we discuss faunal aspects of these stream types.

Flow variability and biofilm metabolism in a regulated lowland river.

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Environmental flows offer the potential to improve the ecological condition of rivers by mimicking elements of the natural flow regime through managed dam releases. An extended period of below average rainfall in the Murrumbidgee River catchment, south-eastern Australia, has resulted in the modification of release patterns for environmental flows. A regime of large releases interspersed by extended low flow periods has been replaced by prolonged periods of low flows with low level variability. Determining the ecological responses to different release patterns is paramount in assessing the effectiveness of managed flows for restoring riverine ecosystems. This study experimentally examined the effect of varied inundation and desiccation regimes on biofilm metabolism and algal succession on River Red Gum (*E.camaldulensis*) substrata in lowland reaches of the Murrumbidgee River.

Blocks of River Red Gum were placed at a sub-surface depth and sequentially harvested over a 75 day period. Replicate blocks were either permanently inundated for the duration of the experiment or experienced a regime of 5 days inundated/9 days desiccated and 11 days inundated/21 days desiccated for the 75 day period. Maximum net primary productivity was achieved after 29 days permanent inundation from biofilms dominated by filamentous green algae. There was a significant positive correlation between net productivity and biofilm chlorophyll concentration in permanently inundated blocks. After 75 days the 5/9 regime produced a heterotrophic biofilm with low algal diversity. The 11/21 day regime produced a biofilm with high algal diversity and a net productivity similar to the permanently inundated blocks after 29 days. Flow variability clearly has the potential to alter fundamental ecosystem processes and must be taken into account when implementing environmental flows in regulated rivers.

SPATIAL AND TEMPORAL VARIATION DURING DRYING IN NUTRIENT AND PERIPHYTON COMMUNITY IN A SEMIARID STREAM (SPAIN).

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In this study, we analyze the effects of water loss in periphyton communities and nutrient concentration mainly, during drying. This work was carried out in a ephemeral stream, located in the southeast of Spain, one of the most arid regions (annual rainfall less than 250 mm) of the Iberian Peninsula. We chose a 100 m section in middle-reach of Chícamo stream, where the flow is continuous. The different habitat types we sampled were visually distinct units within the stream, but with an apparent physical uniformity. As a quantitative descriptors of habitat heterogeneity, we used the current velocity, substrate type (bedrock, stone, gravel, sand and silt), depth and the presence or type of primary producers. Three samples of periphyton and water were weekly collected in each habitat type, during the summer of 1999 (from July to October), allowing to get measures of periphyton biomass (AFDM, chlorophyll "a") and nutrient concentration (nitrate, nitrite, ammonium and phosphorus), apart of other physical parameters as oxygen concentration, salinity, depth, water temperature, current velocity and conductivity. All the habitat types present each week within the stream reach were cartographied "in situ" and subsequently digitised. The spatial and temporal variations of different parameters were also studied. We describe changes in spatial pattern of stream water nutrient concentration over successional time. The results could indicate that the limiting nutrient, phosphorus, is consistently less spatially heterogeneous than nitrogen. Furthermore, we noticed a decrease in the number of habitat types present each week due to water loss in stream; the periphyton biomass measures of these habitat types were similar.

BIOAVAILABILITY OF PHOSPHATE IN THE SEDIMENT OF A TEMPORARY POND

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Most ponds from the Doñana National Park (SW, Spain) are shallow temporary freshwater bodies on eolian sands. Sediments play an important role in these fluctuating environments that switch from aquatic to terrestrial habitats following flood and drought cycles. The P-fractional composition of sediments was determined by the EDTA method (Golterman, 1996) in a small temporary pond at 3 different sites during the wet and dry seasons along 3 successive years (1997-1999). Sediments in the floodplain site were covered by grass while the littoral site was mostly bare. The sediment at the centre site experienced drastic changes in redox potential (from –290 to +236 mV) during the study period. Fine sediments (<0.1 mm) were rich in organic matter (9-25%) and total P concentrations were high (182-655 mg kg^{-1} dw.), especially at the open-water and floodplain sites. The sediment phosphate composition was dominated by P-organic fractions at all sites. The sediment from the floodplain site was poorer in inorganic-P bound to iron but richer in organic-P compounds extracted with EDTA than the sediment from the centre site. In most cases, the fraction of inorganic-P bound to iron decreased significantly at the end of each dry season ($P<0.05$). Additionally, two organic-P fractions, one extracted with acid and the other with alkali, also decreased significantly at several sites ($P<0.05$). Then, both the inorganic-P bound to iron and certain organic-P fractions can be a source of bioavailable-P in these sediments. The growth of grass and the effect of desiccation could account for the observed changes in the P-composition of the sediments.

Water quality and aquatic macroinvertebrate response to intensified summer droughts and acidification in a Western Australian wetland

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Increasingly the effects of climate change on aquatic ecosystems are exacerbated by human activities within the catchment. Lake Jandabup lies on a groundwater mound which is an important source of public water supply for Perth. Between 1996 and 2000 the wetland experienced declining water levels and shorter periods of inundation. Routine monitoring revealed a decline in the pH of surface waters from around 6 – 8 to around 4 to 5 over this period. Concurrent to the acidification, total nitrogen, mainly in the form of ammonium, increased markedly; total phosphorus initially increased but filterable reactive phosphorus remained very low. Macroinvertebrate family richness remained virtually unchanged, however, there were shifts in community structure; isopods and oligochaete worms became less abundant, molluscs, amphipods and ostracods disappeared, while ceratopogonids (Diptera) and macrothricid cladocerans increased in abundance. There was also a trend towards a greater proportion of the fauna becoming rare during the second half of the monitoring period. Increased exposure of pyritic sediments is likely to be the principal cause of the acidification. Sediment core sampling revealed significant spatial heterogeneity of iron, sulfate and pH within the wetland. It is argued that the ability of the lake to recover will depend on the severity of the exposure and the ability of sensitive biota to disperse back into susceptible parts of the lake.

Flood and Drought — Variable Connectedness Structures Invertebrate Composition in Dryland Rivers: Data from Cooper Creek and Diamantina River

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The main channels of lowland rivers and their floodplain habitats rely on natural patterns of hydrological connectedness to sustain resident biota and ecosystem processes. In `dryland rivers', hydrological connectedness is lost to varying degrees during dry periods when flow may cease. This habitat fragmentation is probably a critical aspect of dryland rivers, contributing to a high degree of habitat heterogeneity in time and space. We collected samples from two major river–floodplain–wetland complexes in the Lake Eyre Basin, central Australia, Goyder Lagoon and Coongie Lakes. Sampling in Coongie Lakes was undertaken at the end of an exceptional period of water-body connectedness imposed by a large flood sequence. In contrast, sampling of Goyder Lagoon occurred after all water bodies had been disconnected for more than one year. Given the two contrasting hydrological histories we predicted that the aquatic faunal composition of the sites and habitat types in the Coongie Lakes would converge, while we should see marked differences in assemblage structure between water bodies in Goyder Lagoon. This was apparent in the separation of sites in ordination analyses; there was poor separation of sites for the Coongie Lakes data, while sites separated readily in the Goyder Lagoon database. The differences in assemblage composition between disconnected sites may reflect different successional trajectories occurring within a water body after hydrological isolation. Disconnection and drying of a water body — whether natural or as a result of water abstractions by humans promotes disconnectedness in arid systems. Thus, the unpredictable cycle of drought and floods underpins invertebrate assemblage composition at spatial scales ranging from habitat to entire wetland.