Not for all seasons: Why timing is critical in the design of visitor impact monitoring programs for aquatic sites within protected areas.

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Abstract

Environmental monitoring is an essential feature of environmental assessment and natural resource management. Whilst the focus of monitoring programs is often on the response of chosen variables to a disturbance of particular concern, it is also important to consider the variability of disturbance pressures in relation to the variability of ecosystem state. In this paper, we discuss the need to relate environmental variability to disturbance variability in small-scale monitoring programs designed to assess the impact of short-term pulses of visitors on the condition of aquatic ecosystems in protected areas. We use data from protected areas from six Koppen climate zones in Australia to highlight the fact that peaks in visitation do not always coincide with existing monitoring protocols or with optimal times for monitoring on the basis of environmental variability, particularly in relation to rainfall and temperature and hence, likely biological activity. We highlight how recognising the interaction between disturbance variability and environmental variability will greatly enhance the power of monitoring programs and substantially improve our capacity to detect responses to temporally pulsed disturbances. Analyses of this type, undertaken before the establishment of monitoring programs, will yield higher quality information and a better return on monitoring investment for natural resource managers.

Keywords

Press, pulse, seasonality, disturbance, climate, national parks

Introduction

Monitoring has become a major feature of environmental assessment and natural resource management over past decades, largely as part of a shift towards ensuring the sustainability of ecosystems and maintaining their ecological resilience in the face of increasing anthropogenic pressures (Bunn et al. 2010). In their comprehensive overview of monitoring approaches for aquatic systems, Downes et al. (2002) conclude that the major reason for environmental monitoring is to detect the effects of a perturbation; a perturbation consists of a “disturbance”, the disturbing force or stress, and a “response”, the way in which the ecosystem (or a selected component of it) responds to the disturbance or stressor.

Large-scale environmental monitoring programs are commonly designed to quantify the response of selected indicators (e.g. in the case of water quality, most often nutrient concentrations, water clarity or algal biomass) to chronic and spatially pervasive disturbances, usually ones that are associated with catchment land use and/or point sources of pollution (Downes et al. 2002, Bunn et al. 2010). Monitoring designs such as these almost always deal with stressors known as “press disturbances”, i.e. those where the stress is essentially constant or increases progressively through time (Lake 2000, Figure 1). Disturbances that increase progressively represent a particular class of press disturbance, commonly called “ramp disturbances” (Lake 2000). In the case of both press disturbances and ramp disturbances, the nature and intensity of the disturbance itself does not change over short- to medium-time frames, even though temporal changes in the spatial extent of particular land use types and/or the number and nature of point sources may take place (Lake 2000).

In many cases, however, the disturbance is acute or spatially or temporally variable. These types of disturbances are known as “pulse disturbances”: an acknowledgement that the disturbance pressure pulses on and off (Figure 1, Lake 2000). Unlike the case with press or ramp disturbances, pulse disturbances may afford ecological systems and their component species time, either on predictable or highly variable cycles, to recover from the disturbance (Lake 2000). Nevertheless, pulse disturbances (especially events like floods and storms) often represent critical events that strongly influence the species diversity and ecology of aquatic ecosystems (Lake 2000). They are, however, intrinsically more difficult to study, as the stressor is not present all the time or at the same intensity. As a result, the detection of impacts from pulse disturbances, particularly if the pulses are spatially and temporally highly restricted, represents a completely different challenge to monitoring the impact of chronic, broad scale disturbances that typically attract monitoring investment (Hadwen et al. 2010).

It is clear that, for environmental monitoring programs to be successful, it is essential to understand and account for environmental variability, both in terms of the disturbing stressors and in terms of the ecological responses that accrue (Boulton 1999, Downes et al. 2002, Sheldon 2005). Because of this, most monitoring programs aim to control or reduce the effects of environmental variability by timing the collection of samples such that they do not coincide with extreme environmental conditions. A good example of such fine-tuning of sampling regimes is the freshwater component of the Ecosystem Health Monitoring Program (EHMP), a substantive, regional-scale aquatic monitoring program developed to test the impacts of land use change and diffuse runoff on streams across southeastern Queensland, Australia (Bunn et al. 2010). Since its inception in 2001, this program has developed rules based around environmental variability, particularly pertaining to the seasonal variability of river flows in the region, and has set conditions around the timing of sampling so that the long-term effects of land use disturbance rather than the shorter-term effects of variable flow on river health indicators (which can be major – see Rose et al. 2008, Coleman et al. 2011) are detected. In the EHMP program sampling is restricted to spring and autumn, in order to avoid the high (summer) and low (winter) rainfall periods in this part of sub-tropical Australia. Moreover, monitoring is suspended or delayed if significantly large rainfall events occur during the preferred spring and autumn sampling periods, again in an attempt to ensure that the monitoring data reflect land use condition and not the effects of temporarily increased river discharge after storms. This specific example supports the generally held view that environmental variability will strongly influence the success of an aquatic monitoring program and that the consequences of significant changes in flow (or complete loss of flow) can outweigh the effects of the target perturbation being monitored (Boulton 1999, Sheldon 2005).

A quite different situation – requiring a quite different monitoring solution – takes place when natural resource managers need to assess the impact of visitors in protected areas. In these cases, the stressor (i.e. factors associated with visitation intensity) is likely to be strongly pulsed rather than chronic and persistent. An extreme example of this is when it is necessary to monitor visitor impacts in and around swimming areas in lakes and streams. Previous studies have highlighted the significance and appeal of relatively discrete and deep aquatic sites, often referred to as "swimming holes", to visitors (Hadwen et al. 2005b, Prideaux et al. 2009). Accordingly, there is a growing concern that it is necessary to monitor the condition of intensively used aquatic sites to ensure that visitors do not have adverse impacts on water quality (including quality from a public-health perspective) and ecological characteristics, particularly given the wide variety of activities (and potential impacts) undertaken by visitors at popular sites (Hadwen et al. 2007, Hadwen et al. 2008, Hadwen et al. 2010).

Attention has been given to the particular issues surrounding the sustainable management of visitor use of protected areas, and how to monitor visitor impacts effectively to assist management and planning. The recently developed IUCN World Commission on Protected Areas (WCPA) evaluation framework (Hockings et al. 2000) aims to assist managers in developing systems and associated indicators for evaluating the effectiveness of their management of protected areas. The IUCN WCPA framework is accompanied by a set of criteria which includes the selection of indicators that are: a) unambiguous, predictable and have a verifiable relationship with the attribute being assessed; b) sensitive to change in the attribute being assessed; able to integrate environmental effects over time and space; c) able to reflect changes and processes of significance to management; d) able to reflect changes at spatial and temporal scales relevant to management; e) cost-effective in terms of data collection, analysis and interpretation; f) simple to measure and interpret; and, g) able to be collected, analysed and reported in a timely fashion (Hockings et al. 2000).

Despite the growing concern about effective monitoring of visitor impacts (Hockings 1998, Hockings et al. 2000, Buckley 2003), the need for aquatic ecosystem monitoring in protected areas is very rarely supported by the implementation of appropriate monitoring programs for pools, lakes or streams that attract large numbers of visitors. In fact, we have recently shown from a survey-based research project that, across very large parts of Australia, protected area managers frequently cite the lack of relevant knowledge, expertise and resources as factors that limit their ability to design, implement and interpret monitoring programs for freshwater systems (Hadwen et al. 2012). On top of these limitations and of perhaps even greater concern is the fact that there is no mention of freshwater monitoring in protected area or national park documentation from Queensland, New South Wales or Victoria (Queensland EPA 2001, NSW DEC 2005, Parks Victoria 2007, Queensland DERM 2011). Instead, aquatic monitoring remains the legislated responsibility of agencies outside of the domain of national parks (Environment Australia 2001, Queensland DERM 2010). As an example from southern Australia, we note that the ecological condition of aquatic systems in Victorian national parks is undertaken not with a dedicated aquatic monitoring program that seeks to detect the specific effects of visitation, but by the use of two generic monitoring protocols (Parks Victoria 2007): the first being the Index of Stream Condition, a State-wide and rather insensitive method that was developed to assess the effectiveness of catchment investment over long-term (~ 5 years) intervals and is designed to the applied repeatedly on roughly this time period; the second is the Flow Stress Ranking Index, again a State-wide method, but which in this case seeks to rank rivers on the basis of the naturalness of their flow regimes, measured over long periods of time and likely to be updated only every decade.

Although natural temporal variability in aquatic ecosystems over seasonal and longer timescales is well understood in principle (Lake 2000, Sheldon 2005) and seasonality in visitation to high-use sites in protected areas is well documented (Baum & Lundtorp 2001, Butler 2001, Hadwen et al. 2011), there have, to date, been no cohesive efforts to bring together these sources of temporal variability in the design of monitoring programs around critical ecological and recreational components such as focal swimming holes in protected areas (Hadwen et al. 2012). In fact, although it is also widely acknowledged that environmental monitoring programs can fail for a very large number of reasons (Hockings et al. 2000, Buckley 2003), poor timing is rarely given as one of the factors that lead to failure. In their book on environmental monitoring, Lindenmayer and Likens (2010), for example, note that poor experimental design is often a limiting factor; however they stress inadequate statistical power and inappropriate statistical procedures rather than underlying factors such as inappropriate timing of sample collection. Of the few aquatic ecosystem monitoring programs in protected areas, all that we are aware of adopt temporally regular sampling regimes which do not recognise and are largely independent of environmental or visitation variability (Hadwen et al. 2005a, Parks Victoria 2007). This neglect of timing issues is probably part of a syndrome that “one size fits all” and that “off-the-shelf” monitoring programs can be applied to quite different ecological systems and environmental questions (Lindenmayer and Likens 2010).

In this paper, we outline the implications of environmental and disturbance variability for the successful design and implementation of monitoring programs in protected areas. We present case studies from across Australia that highlight how local environmental conditions and visitation seasonality, in geographically distant regions and across six climate zones, will strongly influence the likely success of small-scale, visitor-impact monitoring programs. Specifically, we ask the question − how might the seasonality of visitation and the temporal variability of aquatic environments inform the design (and influence the success) of monitoring programs in protected areas? We demonstrate that greater attention to the temporal aspects of monitoring designs developed using this approach will help to optimise returns on the relatively small budgets available for visitor-impact monitoring in protected areas (Hockings 1998, Hockings et al. 2000; Buckley et al. 2008).

Methods

Space and time - Characterising the roles of climate and visitation in high-use aquatic sites within protected areas in Australia

Tourism is a highly seasonal industry (Baum & Lundtorp 2001, Butler 2001), and this variability is reflected in the strongly seasonal pattern of visitation to aquatic systems in protected areas across quite different climate zones in Australia (Hadwen et al. 2005, Hadwen et al. 2012). At a finer temporal scale, it is also clear that visitation can fluctuate not only on a seasonal basis but also according to the timing of holidays within a given season and even to the day of the week during a given holiday period (Cole 2001). As a result, the timing, magnitude and duration of visitation pulses can be quite variable at a wide range of temporal scales within a single aquatic site(Figure 2A, B).

At an even finer temporal scale, it is evident that visitation to particular sites in a protected area will not be evenly distributed throughout the day. Instead, visitation will rise throughout the morning, peak in early- mid-afternoon and then fall again in late afternoon as people return to where they are staying or go home (Figure 2B). Given this daily pattern of visitation and the related increase in water temperature during the morning, on purely theoretical grounds we propose that the best time to sample – in terms of both capturing visitor impacts and biological responses to visitation – is mid to late afternoon, during periods of peak visitation. Such a sampling regime may bear no relationship to existing monitoring protocols.

In contrast to the case with temporal variability, the spatial context of visitation in protected areas is generally quite fixed and static, with visitors typically having access only to focal sites either as a result of deliberate management zoning decisions or to more general difficulty of access (e.g. lack of sealed roads). Furthermore, the relatively pristine setting of many of these sites typically ensures that broader spatial influences, such as those relating to geology and topography and land use change, also remain relatively constant and unchanging (Figure 3). These particular circumstances suggest that the primary influences on drivers of ecological responses – temperature, light and nutrients – will be influenced predominantly by forces associated with variability in climate and visitors (Figure 3).

Given the context described above (and presented in Figure 3), coupled with the specific goal in protected areas to develop effective visitor-impact monitoring programs, we propose that it is likely to be more important to focus on temporal aspects of visitation and environmental variability than it is on the spatial elements. To some degree this is true of many programs designed around detecting the impacts of pulse and point-source disturbances, although upstream and downstream spatial considerations are also vitally important in the design of monitoring programs to facilitate the detection of impacts and to determine limits of acceptable change and spatially-resolved management responses in streams (Peterson et al. 2011).

We illustrate the conjectures made above by using visitation data collected from national parks in each of the six Koppen climate zones (www.bom.gov.au) in eastern Australia and, in particular, by selecting a small number of sites that represent contrasting seasonality in climate and patterns of visitation. We used these data to examine the synchronicity of seasonality with visitation intensity in order to identify optimal monitoring program designs to assess visitor impacts at heavily used aquatic sites within these different types of protected areas. Visitation statistics were collected from the relevant State agencies, as described in Hadwen et al. (2011). The national parks selected were Iron Range NP (equatorial zone; Queensland), Lakefield NP (tropical zone; Northern Territory), Great Sandy NP (subtropical zone; Queensland), Carnarvon NP (grassland zone; Queensland), Diamantina NP (desert zone; Queensland) and Cradle Mountain NP (temperate zone; Tasmania).

Characterising environmental variability

Broad-scale environmental variability is often driven by climate and, on shorter timeframes, weather events (Hadwen et al. 2011). Whilst the latter are hard to predict and account for in monitoring programs, current patterns of climate-driven variability in riverine ecosystems are easily understood and accounted for from long-term records in most locations (Kennard et al. 2010). Since seasonal changes in temperature and rainfall are likely to significantly affect the ecological response of an aquatic ecosystem to visitor impacts (Figure 3), these two parameters (and their inter-annual variability) should be well understood and characterised during the design phase of monitoring programs.

Analyses

We compared the timing of rainfall, temperature and visitation across the six selected national parks to identify periods of the year during which visitor impact monitoring is optimal for each climate zone. We considered optimal sampling periods to occur when visitation was relatively high, rainfall was relatively low and temperatures were relatively high. Whilst this combination of conditions does not always exist in practice, our rationale was that from an environmental perspective, periods when rainfall is likely to be low relate to periods during which significant flow events are unlikely to disrupt the effects of the visitor disturbance in question (Bruno et al. 2010, Gallo et al. 2010). Similarly, since temperature is strongly correlated with biological activity (Clapcott et al. 2010, Ferreira & Chauvet 2011), periods with higher temperatures were considered optimal to the success of monitoring within these protected areas, as ecological indicators will be most responsive when biological activity is highest.

Results

When to monitor for visitor impacts?

The ebbs and flows of environmental and visitation variability differ between equatorial, tropical, subtropical, grassland, desert and temperate climate zones in eastern Australia (Figure 4). Climatologically, summers are wet and winters are dry in northern Australia (covering the equatorial, tropical and subtropical zones) and the reverse is true in southern Australia (temperate zone). In the remaining two climate zones, desert and grassland, summers are typically wetter than winters, but there is also significant interannual variability in rainfall and summer rainfall is less predictable than in the more coastal climate zones. Overlaying the patterns of environmental and visitation variability provides a means to facilitate the identification of the optimal times to implement visitor monitoring programs (Figure 4). This section of the Results therefore examines the temporal variability in climatic variables and visitation and identifies the periods during which tailored visitor impact monitoring has the greatest likelihood of yielding meaningful data.

For the equatorial case-study destination, Iron Range National Park, visitation is both strongly seasonal and highly correlated with the climatological variability in the region (Figure 4A). More than 50% of the annual visitor numbers in this protected area occur in July and August, and sharp declines in visitation are associated with the high rainfall and maximum temperatures throughout the summer dry season, which extends from November through to April (Figure 4A). The strong seasonality in visitation highlights the case for temporally constrained and focused visitor impact monitoring in winter and spring (between July and October each year).

For the tropical Queensland destination, Lakefield National Park, peaks in visitation occur during winter to early spring (June to October) (Figure 4B). These peaks coincide with the lowest period of rainfall and although maximum temperatures are also low during this period, they are sufficiently elevated for biological activity to occur in standing and running waters at these times. These seasonal patterns of disturbance (visitation) and environmental (rainfall and temperature) variability suggest that the most successful monitoring of visitor impacts would be conducted during winter and spring (June to October). Conversely, the very high rainfall and comparatively low visitation during the summer and autumn months (November to May) suggests that any monitoring during this period is unlikely to yield meaningful data on visitor impacts.

For the subtropical Queensland case-study destination, Great Sandy National Park, there is less marked seasonality in rainfall than observed in the tropical Lakefield National Park (Figure 4C). Furthermore, visitation variability is tri-modal and has been shown to relate more to periodicity of school holiday periods than it does to seasonal changes in climatic conditions (Hadwen et al. 2011). On the basis of these seasonal patterns in visitation and environmental variables, monitoring from spring to early summer (September to December) offers the greatest promise in terms of yielding valuable visitor-impact data.

Visitation to the grassland zone case-study destination, Carnarvon National Park, is dominated by visits in the cooler months (April to September) when daytime maximum temperatures are moderate and it is unlikely to rain (Figure 4D). In addition, slightly elevated peaks in visitation occur around the typical school holiday months of April, July and September (Figure 4D). The low rainfall and high visitation between April and September suggest that this part of the year offers the best opportunities for detecting visitor impacts.

As was the case for the equatorial and tropical destinations, visitation to the desert zone case-study destination, Diamantina National Park, is strongly seasonal, with visitors rarely visiting this protected area outside of the cooler months of the year (May to September) (Figure 4E). This strong visitation seasonality is clearly related to the climatic conditions in the arid interior, with less extreme maximum temperatures and reduced likelihood of rainfall during this period. Visitor impact monitoring should, therefore, be conducted between May and September, when visitation pressure is high and water residence durations are likely to be at their longest.

For the temperate zone case-study destination, Cradle Mountain National Park, visitation and rainfall are negatively correlated (Figure 4F), resulting in optimal monitoring conditions during summer and autumn (November to April). As this period also coincides with the times of year with the highest temperatures, visitor impacts and biological and ecological responses are likely to be measurable during this high use period.

Discussion

Optimising monitoring effort to detect visitor impacts – why timing is so critical

Traditional water-quality monitoring programs, frequently designed to test for ecological impacts arising from long-term, regional-scale changes in catchment use, are almost always spatially and temporally fixed, whereby measurements are taken at set locations and at set and evenly spaced time intervals (Sheldon 2005). In some cases, as noted earlier for the EHMP in southeast Queensland, strictures can be placed on the timing so that sampling takes place only during quiescent or "baseline" climatic conditions; in other cases, sampling is premeditated to occur regardless of the presence (or intensity) of the disturbance or stressor.

Such approaches seem to hold very largely also for aquatic monitoring programs in protected areas, if in fact a dedicated monitoring program exists at all. We have shown earlier that, in Victorian national parks, the condition of aquatic systems is assessed with two "off-the shelf" protocols that were designed not to detect visitation impacts specifically, but to guide more general regional investment strategies. An example of a program designed to test visitation effects is the water quality monitoring of the heavily visited freshwater lakes on Fraser Island, a World Heritage Area in Queensland. In this case sampling is conducted quarterly and from a single location in the middle of each lake of interest (Hadwen et al. 2005b). Clearly this approach will not be able to detect the spatially restricted (usually littoral) and seasonal flux of visitors that use (and may affect) these lakes (Hadwen et al. 2005b). Instead of this generic approach, we propose a new set of more targeted protocols whereby variability in both the natural environmental and in visitation are examined prior to the design and implementation of a visitor-impact monitoring program. Such an approach offers the most cost-effective and rational approach to detecting visitor impacts in relatively pristine environments. Whilst this approach offers useful insights into designs for the monitoring and management of protected areas generally, it is particularly important and relevant when considering heavily visited aquatic sites within protected areas, as temperature and water flows and/or residence times are critical to how disturbances will be processed and manifested within the aquatic ecosystem (Dahm et al. 2003).

Not all locations are the same – the need for local understanding

We have argued that over both seasonal and shorter (weekly and even diel) timescales, there are optimal times during which monitoring of visitor impacts should be conducted on the basis of both visitation variability and the variability of the ecosystems being monitored. Critically, these times can differ among sites and regions (Figure 2) and are likely to be influenced by the types of visitors and the range of recreational activities of participants (Hadwen et al. 2005a, Hadwen et al. 2007). Therefore, we suggest that analysis of the spatial and temporal characteristics of visitation and environmental variability is required for each monitoring location prior to the establishment and implementation of a monitoring program. Coupling together our understanding of the temporal aspects of visitor and environmental variability should markedly increase the likelihood of successfully detecting visitor impacts before detrimental ecological changes become significant and/or irreversible. From a management and cost-effectiveness perspective, the adoption of the approach outlined in this paper is likely to ensure that the scarce resources available for visitor-impact monitoring in protected areas are used judiciously in a manner likely to generate the most relevant and important information for natural resource managers (Hockings 1998, Buckley 2003, Buckley et al. 2008).

The specific temporal and spatial aspects of visitor impacts in and around focal aquatic sites makes the monitoring of consequences relatively straightforward (often using a BACI – Before After Control Impact – design; see Downes et al. 2002), and, importantly, significantly different to the approaches taken in terrestrial settings. Indeed, because visitors may not be likely to enter waterbodies all year round (due to water temperatures, local weather conditions and/or seasonality in periods of high use related to school holiday periods etc) there is also some capacity for these natural systems to recover from periods of high use. As a result, impacts in aquatic ecosystems may be temporally short-lived and spatially restricted around focal areas of high recreational activity; these temporal and spatial aspects are quite different to those associated with visitor impacts in terrestrial settings, which are generally considered to have longer-lived consequences, due to the cumulative and long-term effects associated with disturbances such as trampling and camping (Cole & Monz 2003, Pickering & Hill 2007).

Although visitor-induced disturbances may occur as temporally restricted “pulses”, monitoring the ecological condition of heavily used aquatic sites must remain an important component of protected area management, particularly given the importance of focal or iconic recreational sites to visitors. For example, Hadwen and Bunn (2004) showed how visitors can alter the structure of lake food webs through changes in food resource (algal) availability and palatability. In that study, subtle changes in food web functioning were only detected through the use of a broad suite of ecologically meaningful indicators applied at appropriate times of year. To this end, ongoing monitoring of a wide suite of indicator variables can provide resource managers with valuable information regarding not just the response of the environment to pulsed visitor disturbances, but also longer-term effects on the structure and functioning of aquatic environments (Hadwen et al. 2008).

Conclusion and implications

Focussed monitoring of the condition of heavily used aquatic sites within protected areas is rarely undertaken, despite the importance of these sites to visitors for diverse recreational activities and their likely ecological and biodiversity significance (Hadwen et al. 2005a, Parks Victoria 2007, Hadwen et al. 2012). Our findings emphasise the importance of understanding the temporal and spatial characteristics of both visitation and natural components of the ecosystem to optimise monitoring design in relatively pristine aquatic sites. It builds on the work of Sheldon (2005), who articulated the need to incorporate environmental variability into ecological monitoring designs for intermittent and ephemeral streams and rivers, but that work was not conceived in the context of tourism-related impacts. In this paper we stress the need to explicitly acknowledge spatial and temporal variability (both of visitors and environmental variables) to ensure a good return on monitoring investment in and around heavily visited aquatic sites within protected areas.

The approach promoted in this paper, whereby knowledge of variability in visitation is overlaid with variability in ecological processes (often driven, in turn, by variability in broader environmental factors) to determine optimal monitoring periods, can aid protected area managers in the design of monitoring programs that will yield high quality information relating to visitor impacts at focal sites. Insightful monitoring designs developed using the recommended approach will also optimise returns on the relatively small budgets available for visitor-impact monitoring in protected areas (Hockings 1998, Buckley et al. 2008). Ultimately, an improved understanding of the consequences of local visitor and environmental variability will better serve the needs of natural resource managers who are charged with the task of balancing the conservation and tourism/recreation objectives of popular sites within protected areas (Bentrupperbaumer et al. 2006, Hadwen et al. 2007).

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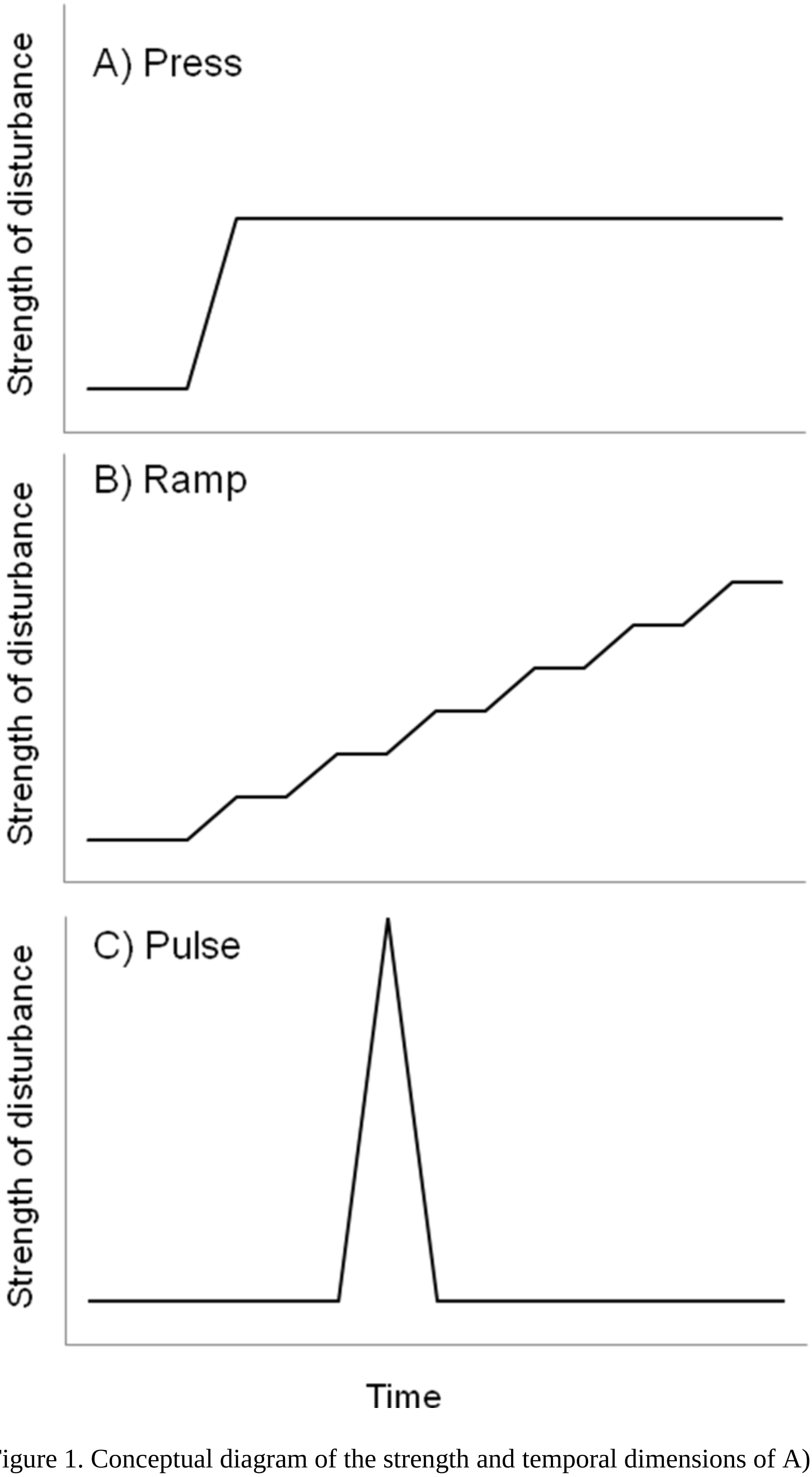

Figure 1. Conceptual diagram of the strength and temporal dimensions of A) press, B) ramp and C) pulse disturbances.

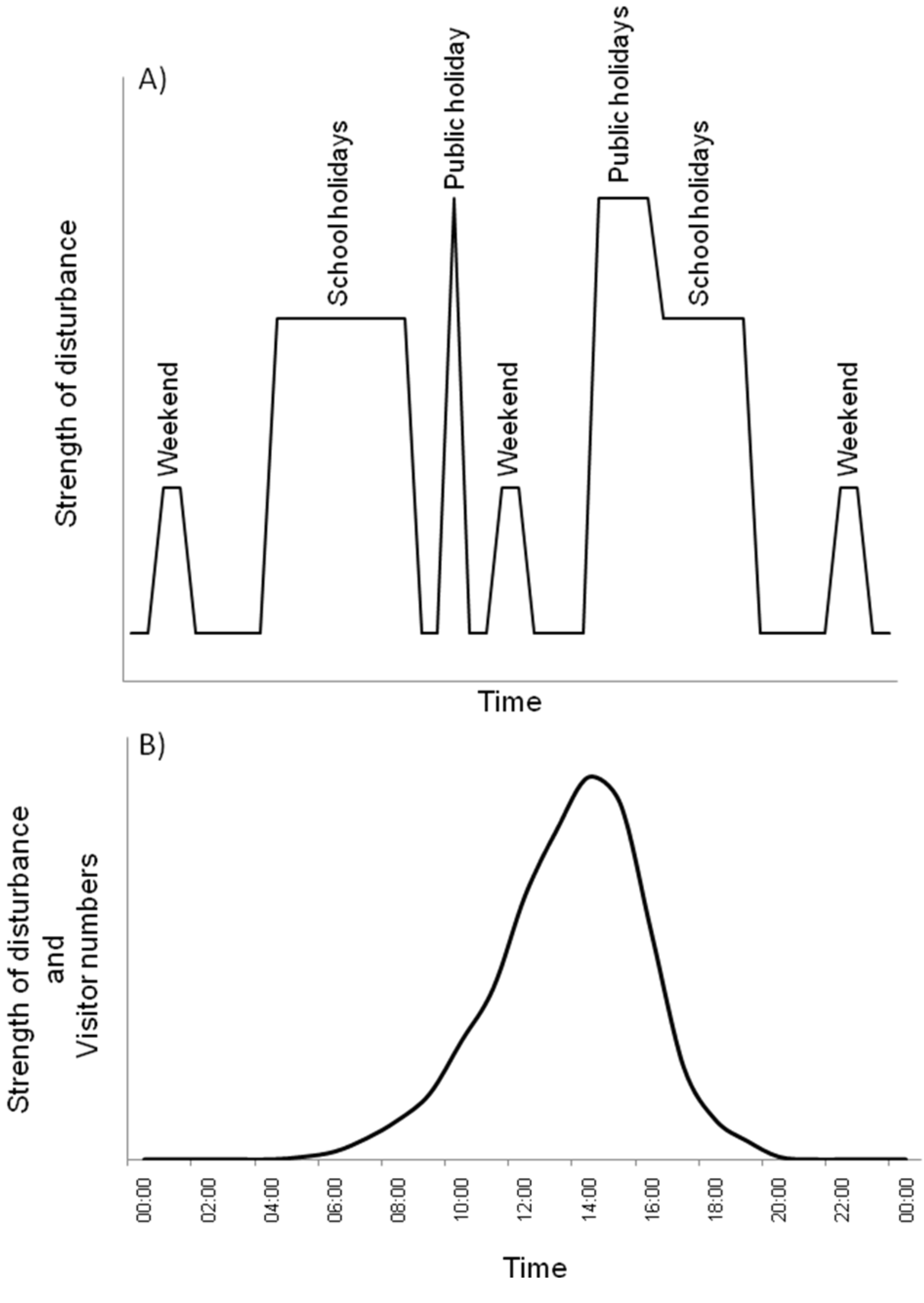

Figure 2. Conceptual diagrams of the variability in visitation to sites within protected areas on A) monthly, and B) daily time scales.

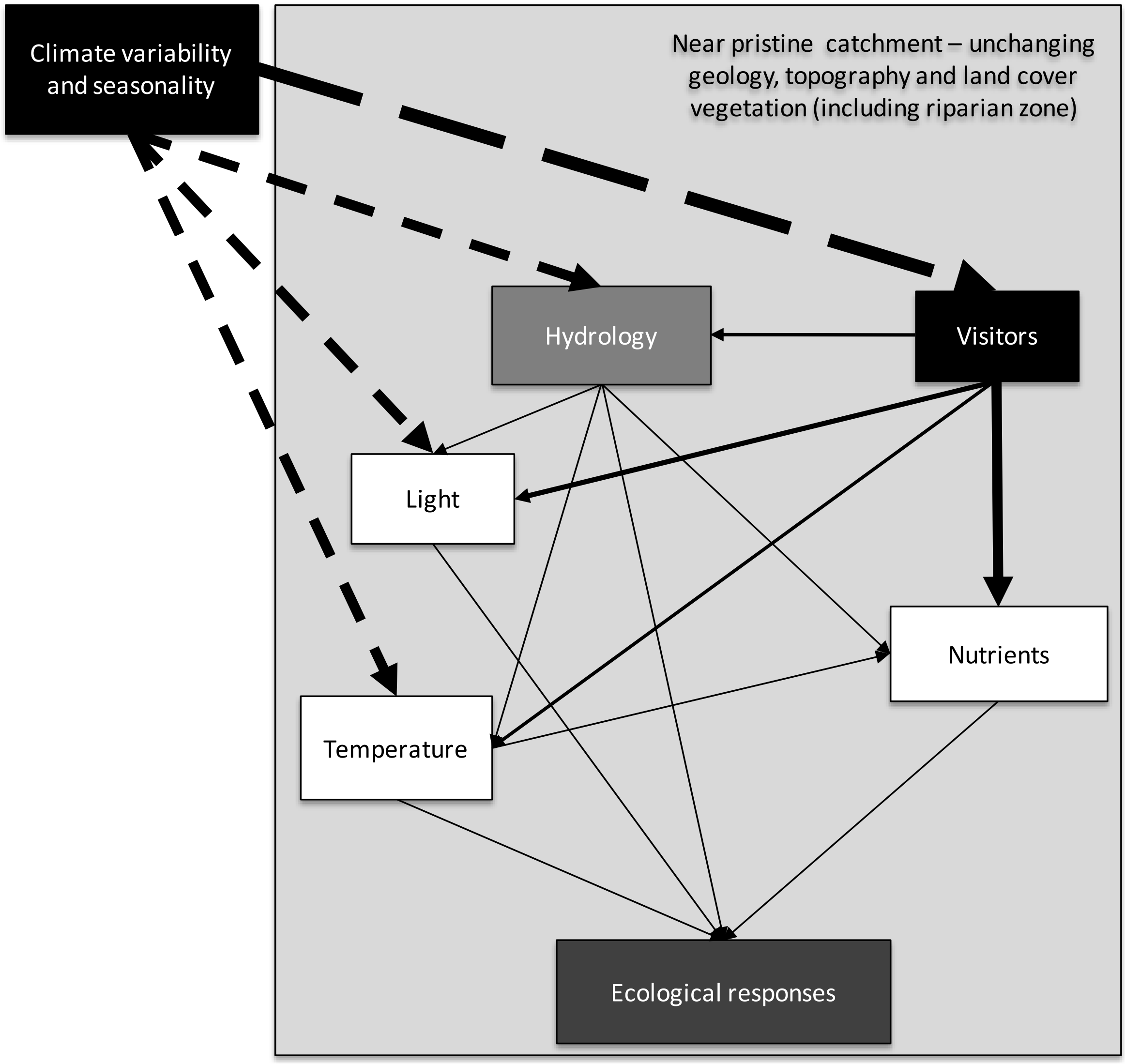

Figure 3. Conceptual diagram of the role of climate and visitors on drivers of ecological responses in high-use swimming holes in protected areas. The solid and dashed bold lines highlight the pathways by which visitors and climate, respectively, can affect hydrology, temperature, light and nutrient conditions and therefore, ecological responses. The comparatively minor effect of geology, topography and riparian vegetation relates to the fact that protected area sites typically occur within relative pristine environments, in which these environmental factors do not tend to change substantially through time.

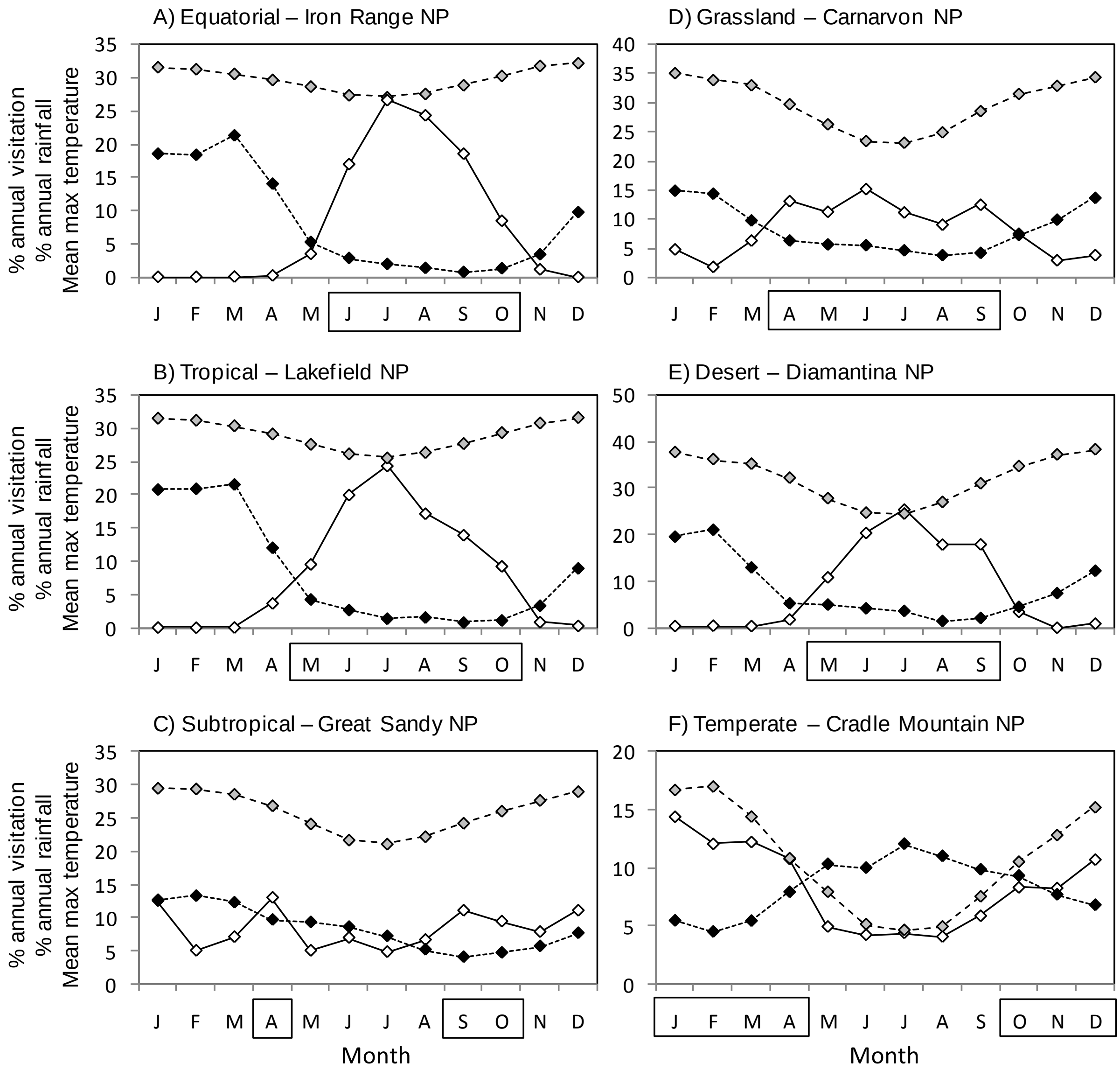

Figure 4. Patterns of annual variability in percent of annual visitation (solid line, open diamond), percent of annual rainfall (dotted line, solid diamond) and mean maximum temperatures (dashed line, grey diamond) for all six Koppen Climate Zones in eastern Australia. A) Equatorial – Iron Range NP, B) Tropical – Lakefield NP, C) Subtropical – Great Sandy NP, D) Grassland – Carnarvon NP, E) Desert – Diamantina NP, and F) Temperate – Cradle Mountain NP. Boxed months are those during which monitoring of visitor impacts and their biological and ecological consequences is optimal on the basis of visitation and environmental variability.