EVALUATING A BENTHIC INDEX OF BIOTIC INTEGRITY (B-IBI) TO MEASURE ECOLOGICAL INTEGRITY IN PACIFIC RIM NATIONAL PARK RESERVE OF CANADA

by

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Title of

Evaluating a benthic index of biotic integrity (B-IBI) to measure ecological integrity in Pacific Rim National Park Reserve of Canada

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Abstract

The ease of application and effectiveness of a multimetric benthic index of biotic integrity (B-IBI) was evaluated for use as an ecological integrity monitoring tool in coastal National Parks of Canada. The B-IBI was developed in three phases: 1) analysis of land use impacts to select study watersheds along a gradient of disturbance; 2) collection and identification of benthic macroinvertebrates from study streams; 3) multimetric and multivariate analysis of benthic invertebrate data to evaluate the performance of the B-IBI approach for monitoring the ecological integrity of streams in Pacific Rim National Park Reserve of Canada, on the west coast of Vancouver Island.

Land use impacts were analysed from Landsat-7 ETM+ satellite images. Potentially appropriate metrics were chosen through a literature review and evaluated by comparing metric scores with watershed impact scores for each study watershed. The ten best metrics for the study region were combined into a benthic index of biotic integrity for Pacific Rim NPR, and each study stream was given a biotic integrity score derived with this index. Additional analysis of the macroinvertebrate assemblages was conducted using multivariate ordination, in order to compare multimetric and multivariate approaches.

The multimetric B-IBI approach produced relatively high overall biotic integrity index scores for most study creeks, but the scores did not correlate well with impact scores determined from satellite image analysis. Multivariate analysis of the macroinvertebrate data separated sites according to environmental variables, but did not separate sites based on impact scores from satellite image analysis. This may be attributable to a lack of impacts in the macroinvertebrate communities, but it is argued in this report that the results are better explained as a failure of the B-IBI method to detect impacts. The B-IBI approach could be improved by increasing sampling effort enough to determine reference conditions for macroinvertebrate assemblages in Pacific Rim NPR. Future studies will need to include streams further outside the boundaries of the Park, to sufficiently increase the number of samples for reliable measurement of the ecological integrity of Park watersheds.

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I thank my family, for taking me to meet my first bugs in the Muskokas.

And I thank Josha, for helping me get this far.

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1. Introduction

> **4.** (1) The national parks of Canada are hereby dedicated to the people of Canada for their benefit, education and enjoyment, subject to this Act and the regulations, and the parks shall be maintained and made use of so as to leave them unimpaired for the enjoyment of future generations.
>
> Canada National Parks Act (2000, c. 32)

Leaving National Parks unimpaired for future generations is a complicated goal. What is impairment? Can we maintain and make use of National Parks without fully understanding their parts and processes? Can we understand without directly measuring these things? Can we measure what we do not understand? In order to deal with such questions, Parks Canada has taken on a mandate of ecological integrity (Parks Canada 2000a). Initially, two vague terms were used to define each other – ecological integrity was simply the opposite of impairment (Zinkan *et al.* 1990). A decade of discussion brought some clarity to the issues, and for the new millennium ecological integrity has been defined more precisely in the Canada National Parks Act (2000, c. 32):

> **2.** (1) "ecological integrity" means, with respect to a park, a condition that is determined to be characteristic of its natural region and likely to persist, including abiotic components and the composition and abundance of native species and biological communities, rates of change and supporting processes.

Defining the goal of ecological integrity is only the first step toward achieving it. Were Parks Canada to re-establish the National Parks system from scratch, they might take a more systematic approach and attempt to create a self-sustaining system of protected areas with the principles of ecological integrity and sustainability inherent in their design. In reality, the existing system of National Parks is ecologically troubled

(Parks Canada 2000a). Canadian Parks face "death from a thousand cuts", even as the system appears to progress toward completion (Searle 2000). Since so much of the ecological integrity mission is *post hoc*, Parks Canada is left struggling to repair past damage and avoid future degradation. The chosen approach for this task is science-based environmental management (Parks Canada 2000b). This program is best described as adaptive management based on top-down measurement of state and process variables, combined with bottom-up experiments to understand cause and effect relationships (Bell and Morse 1999). This may be the best possible approach available to the caretakers, stakeholders and users of Canada's National Parks, but success is far from guaranteed. Park managers and planners are seeking the balance that will maintain parks "unimpaired for future generations", but in a world of increasing development and ecological disturbance it will require increased commitment to preventing impairment, instead of trying to restore it after the fact.

Protecting ecological integrity with remedial action after impacts are detected is a risky proposition, because success demands that we monitor the right things to detect impacts and react quickly to halt disruptive actions and restore degraded systems. In order to monitor the right things, we need to foresee the impacts of our actions. If we can foresee the impacts of our actions, would we not be better off incorporating sustainability principles into our actions in the first place? If we cannot accurately predict the impacts of our actions, we must assess and manage risk. Where we cannot accept the risk of irreparable damage, we would be better off adjusting our plans to respect such uncertainty. To make decisions that avoid unacceptable possibilities of damage, acknowledging scientific uncertainty, is commonly referred to as "the precautionary principle" (Goldstein 1999). Resource users typically place the burden of proof on the rest of society, whose interests are represented primarily by government, to demonstrate harm from resource use. A precautionary approach would shift the burden of proof to resource users, requiring them to demonstrate that their resource use causes no unacceptable harm.

Many National Parks of Canada, and Pacific Rim National Park Reserve of Canada (NPR) in particular, were not established with the goal of ecological integrity explicitly in mind (Dolan *et al.* 1992), though integrity has since become a primary focus of management. This paradox presents many challenges, as managers pursue ecological integrity in limited geographic areas, established with little thought for a holistic, systemic framework to ensure success. A park boundary that does not include complete watersheds is an impediment to ecological integrity, so long as adjacent lands are managed without specific concern for the ecological components and processes that affect the park (Dudley and Stolton 1999). For example, stream dwelling species within a park may be impacted by siltation from land use practices upstream in the watershed, outside the park (Brooks *et al.* 1997). Human use and activities that may affect ecological integrity within the park are also endorsed by the National Parks mandate. Since Pacific Rim NPR has not been established and managed solely for ecological integrity, EI is not an inevitable consequence of the park's existence.

In the context of our National Parks system, sustainability has been defined largely in terms of the dual mandate for "ecological integrity" and "human enjoyment". The potential for compatibility or conflict between these two management goals is evident throughout the history of National Parks in Canada, as primacy has shifted slowly from enjoyment, in 1885 when Sir John A. Macdonald designated 26 square kilometres that would become Banff National Park, to protection of ecological integrity and enjoyment in our system of National Parks today. Management of the first National Park focused on ensuring tourism and recreational access to the healing and restorative waters of the Banff hotsprings. A philosophy of "appropriate use" emerged in the 1911 National Parks Act, allowing only those businesses that were "absolutely necessary for the recreation of the people" (Page *et al.* 1996). Appropriate use remained a primary direction for National Park management until recent decades, when wilderness was recognised as a feature of the landscape requiring protection.

Canadian parks policy first mentioned ecological integrity in 1979, as a "prerequisite to use" (Searle 2000). In 1988 the Canada National Parks Act was amended to include "Maintenance of ecological integrity through the protection of natural resources shall be the *first* priority when considering park zoning and visitor use in a management plan". However, ecological integrity was operationally defined by parks staff only as "the opposite of degradation" in 1990 (Zinkan *et al.* 1990). Six years later, ecological integrity had been defined but indicators and assessment methods were just beginning to take shape with publication of the 1994 *State of the Parks Report* (Parks Canada 1994b). A subsequent update to the *State of the Parks Report* in 1997 (Parks Canada 1997), followed by the appointment of the *Panel on the Ecological Integrity of Canada's National Parks* (EI Panel) in 1998 demonstrated a genuine commitment to develop the concept and practice of ecological integrity in Canada's Parks. The report of the panel was published in 2000, detailing the challenges inherent in a parks system that had been assembled with inconsistent and inadequate planning for integrity and therefore facing increasing threats from within and outside the parks (Parks Canada 2000a). The second volume of the EI Panel report recommended building ecological integrity through renewal of the Parks Canada Agency to be a knowledge-based organisation with a focus on planning, science, restoration, education, cooperation with outside organisations and First Nations, and a commitment to appropriate use and enjoyment of Canada's National Parks (Parks Canada 2000b). The EI Panel defined ecological integrity as:

> "An ecosystem has integrity when it is deemed characteristic for its natural region, including the composition and abundance of native species and biological communities, rates of change and supporting processes." (Parks Canada 2000a)

This definition paraphrases the Canada National Parks Act, and does not include the line "unimpaired by human-caused stressors" that appeared in previous Parks Canada definitions of ecological integrity (Dolan *et al.* 1992; Parks Canada 1994b; Parks Canada 1997). This change recognises the inclusion of humans within ecosystems. In many Canadian National Parks, First Nations may have altered ecosystems through the use of fire, harvest and settlement (Turner 1999). Thus "what is natural" may be subject to debate, especially when most ecosystems naturally fluctuate on multiple scales. For park managers, "What is desirable?" or "What better maintains a balance of commemorative and ecological integrity?" may be better questions to pose.

Finding an appropriate balance of commemorative and ecological integrity should draw on traditional ecological knowledge and defensible scientific analysis. The field of paleoecology offers insight into past climate, sea levels and landscapes, and the ecological processes and components that they supported. Parallels may be drawn between past, undisturbed ecosystems and current climatic conditions to provide insight into what is desirable now, though human induced global climate change and introduced invasive species creates the possibility that our current and future climate may not be "natural". This complicates the assertion put forth by Angermeier and Karr (1994), that variation in elements attributable to natural processes does not represent a variation in integrity, but variation caused by humans does. Climatic variation on long and short temporal scales is certainly normal, but the extent to which human activities might modify this variation remains to be seen. Climate is an important ecological determinant, and climate change is not likely to be mitigated from within National Parks alone, so park management will be forced to pursue ecological integrity based on a dynamic climatic benchmark. Barring improvements in the potential for "repairing" global warming through CO_2 sequestration (Watson *et al.* 2000), the climate may become an inescapably altered baseline upon which we must attempt to maintain ecological integrity (Bartlein *et al.* 1997; Bolt 2000). For these reasons it is critical to include global processes and their potential future outcomes in park planning and cumulative environmental assessment (Munn 1993).

1.1 Ecosystem-Based Management

In National Parks, sustainability requires that ecological integrity be maintained along with appropriate human use. The policy shift toward ecological integrity has been an important step, but operationalising ecological integrity requires a concurrent shift in the approach to management and decision-making. Parks Canada employs an ecosystem-based approach to management. Grumbine (1994) defined successful ecosystem management as maintaining ecological integrity through the attainment of five goals:

- maintaining viable populations of all native species *in situ,*

- ecosystem representation (within protected areas) of all native ecosystem types across their natural range of variation,
- maintaining ecological processes (i.e. natural disturbance regimes, hydrological processes, nutrient cycles, etc.),
- managing on timeframes long enough to protect evolutionary potential of species and ecosystems, and
- accommodating human use within the constraints above.

Slocombe (1998a) subsequently refined the terminology by differentiating between ecosystem management as the management of ecosystems on a small scale, and ecosystem-based management as a broad scale approach involving consideration of entire systems and processes from local to landscape scale. Woodley (1997) followed this convention with an ecosystem-based approach to protected area management. Woodley indicated that the small size and external threats facing many parks undermines their effectiveness as conservation tools, and therefore he suggests that a larger-scale ecosystem-based management approach is required for any chance at success. Because boundaries for many parks were established along political lines instead of ecological features (Dolan, *et al.* 1992), an ecosystem-based approach requires consideration of stressors from outside park borders and co-operation with local and regional stakeholders.

Pacific Rim National Park Reserve serves as a case study for this report, and it is a poignant example of the vulnerability of parks to stressors originating outside their boundaries. A high perimeter to area ratio and limited jurisdiction over adjacent terrestrial and marine components makes Pacific Rim NPR extremely susceptible to external threats. Many of the Park's watersheds, both large and small, have only their lower reaches protected. Nowhere are landscape approaches more important or more politically challenging than in trans-boundary creeks and estuaries. This includes the anadromous fish that inhabit them, because they depend on interactions among terrestrial, freshwater, marine, and even atmospheric systems (Angermeier and Karr 1994).

Many policy makers outside Parks Canada have also taken up an ecosystem-based approach, but most of them are not focussed on ecosystems for their own sake. An example is the inclusion of biological integrity in US water policy since the early 1970s (Karr and Dudley 1981). In this case, biological integrity was pursued primarily as a means to ensure the quality of the resource for human consumption. This approach to management focuses only on the use value of water, without acknowledging the inherent value of ecological functions or their contribution to human health, wealth and enjoyment. Legislation of ecological integrity as the primary mandate for Canadian National Parks offers the opportunity to step beyond management of ecosystems as a resource for consumption, to protecting intact ecological function for its own sake. While a portion of Canadians may favour this approach, others will demand justification of ecological integrity goals in human terms. We need only consider the vast suite of "ecosystem services" provided by intact natural systems – clean air, water, soil, abundant plants, animals, and other organisms – not to mention the direct use of ecological integrity through recreation and spiritual enjoyment.

Management approaches in Canadian National Parks have passed through a fundamental shift, from simply protecting recreation in unique settings, to maintaining relatively natural systems for outdoor enthusiasts, to a primary mandate of protecting ecological integrity in the face of increasing threats and stresses (Parks Canada 2000a). In order to protect or restore ecological integrity, managers must have methods for assessing it. Since it is not possible to measure every element within a functioning ecosystem, monitoring efforts are typically focused on a few easily measured components or processes within the system, based on the assumption that these components serve as a proxy for the structure and function of the entire ecosystem. These elements that provide information about the larger system are *indicators*. It is important to include functional, as well as structural indicators. While popular media often focus on biological diversity, some authors consider that resource policy is most effective when the goal is protection of biological integrity (Angermeier and Karr 1994), where integrity refers to the components of a system and all of its natural processes. Angermeier and Karr (1994) point out the limitations of focussing on the presence or absence of particular elements, insisting, "Policy should focus on protecting and restoring the organisational processes that generate and maintain all elements." However, processes alone are often difficult indicators to assess, and are unlikely to provide as much information as a suite of inter-related structural, functional, and management response indicators (Bell and Morse 1999).

1.2 Monitoring indicators of ecological integrity

Woodley (1998) outlines four possible cause and effect relationships for anthropogenic stresses and resultant ecological effects (Table 1.).

Table 1. Potential interactions between ecological integrity stresses and effects (Woodley 1998).

	Effects	
Stresses	1. Known stress, known effect	2. Known stress, unknown effect
	3. Unknown stress, known effect	4. Unknown stress, unknown effect

Most monitoring work in Canadian National Parks has focused on cases 1 and 2, because of past management priorities and current logistical constraints. When stresses are known, programs may be established to monitor for known and potential impacts. Case 1 (known stress, known effect) situations could be managed by monitoring the physical, chemical, or biological stressors themselves, or monitoring for the known effects of those stressors. Case 1 situations should be easily managed in National Parks, because Parks Canada has a legislated mandate, public support, and technical knowledge to monitor known stresses and mitigate known effects.

Case 2 (known stress, unknown effect) situations may be more difficult for managers because unknown effects are more likely to be missed or ignored. However, there is good potential for scientific assessment in Case 2, especially where stresses can be controlled or at least measured, so that "before/after control/impact" type experiments may be used to drive a program of adaptive management. Caution must be exercised in Case 2 situations to monitor a broad set of variables, so as not to miss previously unknown effects. Biological monitoring offers advantages in this regard, and will be discussed further, below.

Cases 3 and 4 are often missed in assessments, because unknown stresses with known or unknown effects require a broad, yet sensitive monitoring approach. Concentrating on physicochemical variables alone gives a high likelihood of missing cases 3 and 4 – if a stress or effect is unknown, serendipitously monitoring the affected variables is unlikely. Biological monitoring is more likely to detect unknown effects, because of the integration and expression of stresses and effects in all scales of biotic assemblages. Once effects are determined from broad-scale biological monitoring, stresses may be revealed through further observation and experimentation, including both physicochemical and biological monitoring. In any of these cases, choosing the most functional and efficient variables for monitoring requires that managers identify key variables that will convey the most information about stresses and effects.

Using scientifically defensible criteria to select appropriate indicators is important for maximizing the value of monitoring programs. The Ecological Integrity Panel noted that the "chosen indicator set" in the State of the Parks 1997 Report had not lead to an improvement in monitoring and selection of indicators in National Parks, because many parks had not re-evaluated their monitoring programs in light of the recommendations (Parks Canada 2000b). Pacific Rim NPR is one of the few parks that have responded to this challenge, with the *Workshop on Assessing Ecological Status* held in 1998 (Rowe, *et al.* 1998). Implementing the programs selected during the workshop is limited by financial resources, and possibly by managerial priorities as well. It is important to recognise that monitoring is only one step in an ongoing environmental research program (Fairweather 1999). Such a program must make use of existing data and initiate new monitoring efforts that assess both impacts and stressors, providing compatible data that can be used to evaluate ecological concerns individually and cumulatively.

In order to manage for all four stress/effect cases set out by Woodley (1998) and listed above, "the complexity of biotic systems dictates that integrity assessments should incorporate a variety of indicators (including elements and processes) from multiple organisational levels, and spatiotemporal scales" (Woodley, 1998). Interpretation of indicators and determination of management responses must be based on sound science, yet detecting statistical significance alone is not likely to create effective management. If a state indicator varies proportionally with a process indicator suspected of affecting it, some causative relationship may be suspected. But in biological monitoring, as with most ecological research, tidy, quantitatively proportional relationships are complicated by variation in innumerable environmental variables. For example, if an increase in disturbed area in watersheds (process indicator) consistently corresponds with a decrease in sensitive macroinvertebrate indicator taxa (state indicator), the correlation may indicate a causative impact of watershed disturbance on the macroinvertebrate assemblage (Karr and Chu 1999). However, the relationship could be attributable to any number of spurious correlations, additional unmeasured variables may be linked, and the ultimate ecological importance of watershed disturbances or variation in macroinvertebrate assemblages may be questioned. It is therefore the goal of biological monitoring in general, and the index of biotic integrity specifically, to provide methods for cutting through the unknown and uncertain aspects of environmental degradation, to direct management toward efficient and effective outcomes.

Arriving at efficient and effective management outcomes requires insight into ecological systems, but ecological understanding must be integrated with social and economic realities to determine optimal management practices. In the example of the preceding paragraph, it might be determined that changing invertebrate assemblages, combined with other indicators, gives sufficient evidence that the impacts of watershed disturbance on ecosystem function should be mitigated or avoided. Management response would have to include cooperative agreements with forestry authorities and companies to use harvesting methods that reduce upstream disturbance in Park watersheds, such as riparian buffers or variable retention systems. Management response indicators, such as the proportion of recently disturbed forest in each watershed, should be included in the monitoring program, along with structural and functional ecosystem indicators. All of these indicators must be monitored before, during and after management action is taken. The ideal approach is ongoing and cyclical in this manner.

In the traditional statistical paradigm, much caution is exercised to avoid type I error – false confirmation of a relationship between variables. When this is applied to a typically variable and "noisy" ecological system, relationships between variables are likely to be deemed non-significant. But for practical management purposes, type II error – the failure to detect a relationship when it is real – represents an equally important threat to the ultimate goal of ecological integrity. To manage this risk, policy makers might choose precautionary thresholds that will trigger a management response even with statistically weak relationships between indicators. An alternative is to evaluate quantitatively the uncertainty of indicator values and the relationships between them, using multivariate ordination techniques that draw upon Bayesian approaches to estimate the likelihood of relationships (ter Braak 1995), instead of just declaring them significant or not.

The Ecological Integrity Panel Report (Parks Canada 2000a,b) contains many recommendations for research directions in parks, including recommended indicators and research frameworks previously proposed in the State of the Parks 1997 Report (Parks Canada 1997). The "Parks Canada Assessment Framework" calls for measurement and analysis employing a cascading system of Principle, Criterion, Indicator and Target for each variable. The recommended indicators assess biodiversity, ecosystem function and stressors against targets, and each is linked to higher criteria and principles (Parks Canada 2000b).

Slocombe (1998b) stresses the importance of selecting goals, objectives and specific action plans based both on science and local participation. His paper provides a valuable ecosystem-based framework for setting and implementing goals, and should be consulted directly for the valuable insight it contains:

- Goals should be broad and positive - jobs, environmental protection, self-reliance,
- Specific targets should be associated - levels of wildlife populations, extent of burning, harvest levels, etc., and
- Targets and criteria, and even goals and objectives should be identified through a local, ecosystem-based process.

These guidelines describe a process that would combine park planning with planning for areas outside park boundaries. Given the external origin of many stressors facing a Park like Pacific Rim NPR, a commitment to ecosystem-based management is the only way to address the integrity of park ecosystems.

Grumbine (1994) suggests that in the short term, better interpretation of existing data and further scientific research is required to support existing management policy and indicate improvements necessary to achieve success in ecosystem management. The two greatest barriers to ecosystem-based management are institutional territoriality and weak goals (Slocombe 1998b). Overcoming the cross boundary issues that plague National Parks will require cooperation and relationship building among all park stakeholders. Setting strong goals that avoid complacency and empower efficiently directed change could begin immediately, based on existing research and experience in the parks, to be improved as further knowledge is gained. For parks to overcome ecosystem level threats, leadership must come from within the organisation, with proactive management built around strong, science based goals (Woodley 1997). These qualities will ensure that appropriate indicator data is collected efficiently and used effectively.

Monitoring sustainability indicators is an ongoing process involving feedback between indicators, management response, and policy formation. Indicators should be selected to maximise knowledge about states and processes affecting ecosystem function. Thresholds should be established with defensible science and the precautionary principle, to eliminate degradation and reduce dependence on restoration. State or process indicators that violate thresholds should provoke a management response, and lead to continued analysis of policy and the indicators themselves. The scope of analysis must be broad enough to allow assessment at a range of scales (Kalff 1995). These principles create a feedback loop between management and the ecosystem, facilitated by internally consistent science, and ideally, externally substantiated principles (Fairweather 1999). The entire process should be self-reflective enough to build knowledge about the functioning of the ecosystem, the agency, and the social and economic context in which they operate.

In order to assess ecological integrity at an ecosystem scale, comprehensive yet efficient monitoring approaches are called for in Canadian National Parks (Parks Canada 2000b). An index of biotic integrity based on quantitative population and community scale measures of benthic macroinvertebrates is a candidate for assessing ecological integrity in Pacific Rim NPR. Multivariate analysis of physicochemical and macroinvertebrate data may clarify relationships among streams. Improved effectiveness in assessing the ecological integrity of the park will require a broader monitoring program, including baseline information to describe reference conditions of different stream types within the Pacific Rim NPR region, and ongoing monitoring of a suite of biotic and physico-chemical indicators to detect human impacts and evaluate restoration efforts.

1.4 The case for biological indicators

Biological monitoring offers several advantages over physicochemical monitoring approaches. First and foremost, biological monitoring focuses attention on the ability of ecological systems to support life. In most cases, this biological or ecological integrity is the ultimate goal of monitoring and management efforts. Our concern with various measures of water quality, contamination or disturbance is driven by their effect on the living constituents of an ecosystem. Exceptions to this statement exist – the effect of acid rain on buildings and monuments is of concern to managers of National Historic Sites, for example – though even in this case it is likely that biological monitoring would have given indications of acid rain impacts long before buildings started to dissolve.

Living organisms integrate environmental effects over the time that they live and the space through which they range (Merritt and Cummins 1996). This is typically viewed as an advantage of biological monitoring with benthic macroinvertebrates over point measurements of environmental variables, because benthic macroinvertebrates typically have short generation times and are relatively sedentary (Reece and Richardson 2000). Point measurements of environmental variables record precise information about a specific time and place, which can be important for understanding human impacts and enforcing compliance with environmental legislation. However, living organisms record information about their environment over their entire lifespan and spatial range, with their health, behaviour and presence/absence. As sentinels for environmental impacts, biotic assemblages can be much more sensitive and thorough than spot measurements of abiotic factors, and still offer statistically defensible power to detect disturbance. By no means does this imply that abiotic variables have no value in combination with biological monitoring. Some authors recommend inclusion of biotic, physical and chemical indicators in monitoring programs, in order to include as many variables as possible that have cause-and-effect relationships with stressors (Brooks *et al.* 1998). Other authors seek to include measurements of abiotic environmental variables to more precisely characterize stream catchments and identify reference conditions, in order to properly compare biotic assemblages (Reynoldson *et al.* 2001).

Scale is also an important consideration for biological monitoring. The scale of measurement and the scale at which results will be interpreted should be defensible on theoretical and practical grounds. As with many ecological studies, assemblages are measured on a small scale, over a short period of time, then results are scaled up to represent ecological integrity in whole streams and this is interpreted as a proxy for the entire catchment. This approach is justified, because lotic systems have been shown to integrate the effects of upstream impacts anywhere in their catchments, essentially because water and all the other constituents of the stream flow downhill (Roth *et al.* 1996; Downes *et al.* 2002).

1.5 The Benthic Index of Biotic Integrity

The Index of Biological Integrity (IBI) (Angermeier and Karr 1986) combines multiple indicator metrics into a single numerical index, based on comparing observed biological and ecological patterns to region-specific expectations. A metric is a measure of the biotic assemblage data, such as taxonomic richness, relative abundance of certain taxonomic or trophic groups, measures of individual condition, or other indicators of ecological structure and function. Because the IBI combines a series of metrics into an overall index, it is a multimetric method. *Multimetric* approaches offer advantages and disadvantages relative to *multivariate* approaches, where biotic assemblage data are analyzed for patterns directly with multivariate ordinations, clustering, and other techniques. The multimetric IBI score may be used to rank restoration and management priorities, and where further detail is required, the individual metrics comprising the IBI may be analysed to diagnose specific problems within each study area. Multivariate methods offer advantages in objectivity and statistical power, and often multimetric and multivariate methods are combined to offer the best of both (Resh *et al.* 2000).

IBI has been used around the world, including North America, Asia and Europe, primarily for assessing aquatic systems. Benthic macroinvertebrate indicators have been widely employed in studies of creeks and rivers throughout North America (Karr and Chu 1999). In British Columbia, macroinvertebrate monitoring has been conducted primarily in the Fraser River watershed (Resh *et al.* 2000). The IBI method has not been used in coastal streams of British Columbia before, but IBIs capable of resolving three to five classes of impairment have been developed for streams in the Pacific Northwest United States (Karr and Chu 1999). This project focused on a much smaller area, applying a benthic index of biotic integrity approach to assessing ecological integrity in Pacific Rim National Park Reserve, on the west coast of Vancouver Island.

Application of an index of biotic integrity approach to monitoring streams in Pacific Rim NPR involves five general phases (based on Karr and Chu 1999):

1. Classify streams into homogeneous sets,

2. Select measurable attributes (metrics) that provide reliable and relevant signals about the biological effects of human activities,
3. Develop sampling protocols that ensure the metrics in (2) are measured accurately and precisely,
4. Use analytical procedures to extract and understand relevant patterns in those data, and
5. Communicate the results to park managers, stakeholders and citizens.

Application of the Benthic Index of Biotic Integrity (B-IBI) to Pacific Rim NPR is intended to measure the ecological integrity of streams, as a proxy for overall watershed ecological integrity. Streams are intrinsically linked with their watersheds, both structurally and functionally (Downes, *et al.* 2002). This intimate relationship is most evident in the biotic assemblages found in coastal streams, as they integrate ecological impacts over time (their lifespans) and space (the stream catchment). Because it requires information about biodiversity and environmental variables, construction of a B-IBI contributes to our understanding of ecosystem function in the park, and provides baseline data for comparison with future assessments. The B-IBI provides a relative score for the ecological integrity of each watershed, and more specific information about stream ecology and stressors. The results of the project may be interpreted broadly by ranking streams based on degradation, or narrowly by diagnosing degradation from individual stressors, such as sediment, temperature increase, etc.

The index of biotic integrity approach was first introduced over 20 years ago (Karr 1981). Since then the multimetric biotic index approach has been adopted by a majority of US states, and applied on every continent except Antarctica (Karr and Chu 1999). Because it has living organisms at its core, the IBI approach may be more intuitively understood by managers, politicians and the public. It is also a scalable approach, in that it may be as simple as monitoring EPT richness in the same creek over decades (Baker and Sharp

1998), or as complex as a multivariate, multimetric and reference condition based regional index (Resh *et al.* 2000; Reynoldson *et al.* 2001). By the mid 1990s, the index of biotic integrity could stand up to rigorous statistical analysis, and demonstrate sufficient statistical power to be used in support of management decision-making and enforcement of legislation (Fore *et al.* 1994). At present, more sophisticated statistical analyses, and a willingness to combine multivariate and multimetric methods offers an ever better range of biological monitoring options for resource managers.

Conflicting opinions exist on the most effective approach for assessing ecological integrity in the Pacific Northwest (British Columbia, Washington, Oregon, and Alaska). Some researchers endorse the benthic index of biotic integrity (B-IBI) method (Fore *et al.* 1996; Karr and Chu 1999). Others prefer the more rigorous statistical properties of multivariate analysis (Reynoldson *et al.* 2001). It has also been suggested that the strengths of both multimetric and multivariate approaches may be attained when both analyses are carried out in a complementary fashion – namely the inclusion of ecologically informed metrics in a multivariate ordination (Resh *et al.* 2000). The limited spatial and temporal scale of data collection for this project supports a strong case for using the B-IBI approach, because the data do not meet many of the assumptions underlying multivariate methods. The most problematic example of this is that the number of variables (taxa) outnumbers the number of cases (study sites). Despite these limitations, a hybrid multimetric/multivariate analysis was used to permit broader exploration of any information that could be extracted from the data.

2. Methods

2.1 The Study Site: Pacific Rim National Park Reserve

Pacific Rim National Park Reserve of Canada comprises three geographically separate units on the west coast of Vancouver Island, British Columbia, Canada. Figure 1 shows the location of the Long Beach Unit, to the northwest, and the West Coast Trail Unit to the southeast. The Broken Group Islands, an archipelago of islands in Barkley Sound, lies between the Long Beach and West Coast Trail units of the Park. Creeks on the islands of the Broken Group are typically very small, and many are ephemeral or seasonal. Therefore, creeks in the Long Beach and West Coast Trail Units were selected for this study. In order to minimize ecological variation among creeks, easily assessed attributes such as watershed size, the presence of lakes, qualitative measures of gradient, and the extent of development in each watershed were determined from discussions with Pacific Rim NPR staff and GIS analysis. Study sites were chosen by a process of elimination where creeks with anomalous features were eliminated, leaving a set of study creeks that are generally similar. The study creeks are 3rd or 4th order streams (Strahler 1957), with moderate gradients, minimal snowpack, no large lakes, and year round flow. Some of the creeks selected were not able to be sampled because of physical access restrictions (e.g. Billygoat Creek in the West Coast Trail Unit (WCTU), or inappropriate substrate (e.g. Sandstone Creek in the WCTU).

According to Muller (1974), "Pacific Rim" is an apt description of the geological formations underlying the creeks in this study, and the following is based on his assessment of the Park's geology shortly after the agreement for Pacific Rim NPR was signed in 1970. The bedrock was formed in the Mesozoic era, between 200 and 100 million years ago, on the floor of the Pacific Ocean along the continental slope or "rim" of North America. Between 100 and 60 million years ago the rocks were compressed and crumpled during severe fault-movements along the continental margin. In geologically recent time these rocks were uplifted above sea level and given their overburden of glacial till and modern deposits of sand and sediment. The suite of rocks outcropping in the Long Beach Unit are not known elsewhere on the BC coast, but are found in Alaska and California, in the United States.

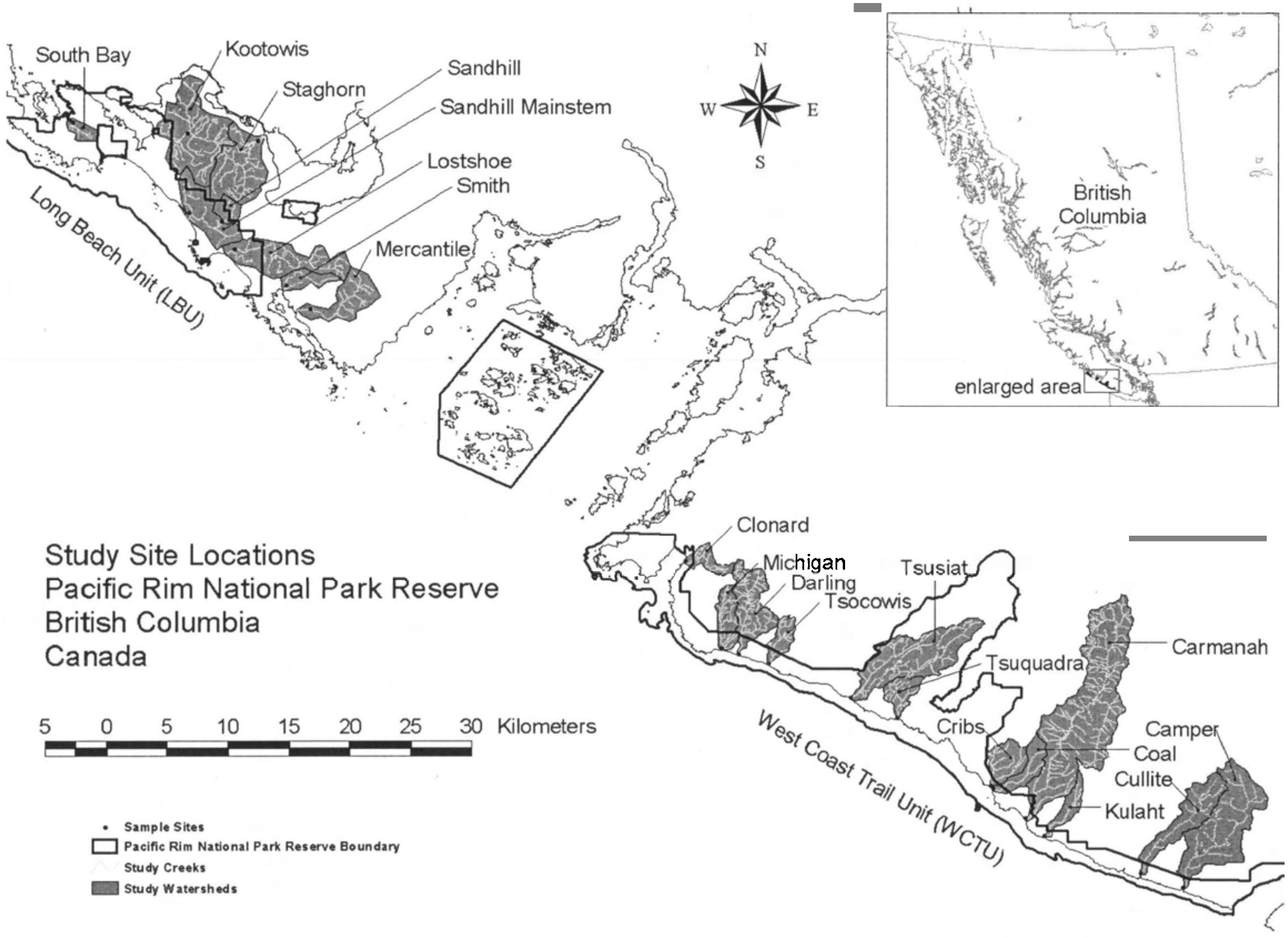

Figure 1. Map of Pacific Rim National Park Reserve of Canada, showing study watersheds and sample sites. ©Baron, 2003.

The study watersheds in the Long Beach and West Coast Trail Units of the Park are located primarily in the coastal western hemlock (CWH) biogeoclimatic unit (Green and Klinka 1994). The study sites are all close to the outflow of each creek, placing them in the very wet southern hypermaritime variant (vh1), with the upper watersheds of some study creeks located in very wet maritime (vm1 and vm2) variants, and the possibility of headwaters in the mountain hemlock moist maritime variants (MHmm1 and mm2) (Green and Klinka 1994). These zones are distinguished by a very wet, mild climate, as the coast receives weather patterns from the Pacific Ocean. Western red cedar and western hemlock are dominant, with coastal Douglas fir at higher elevations. Salal and a suite of V*accinium* species dominate the understory.

The study streams may be divided into two general ecotypes, the steep, fast flowing, low nutrient streams of the West Coast Trail Unit, and the slow, tannic, meandering streams of Kennedy Flats and the Long Beach Unit. All of the study streams are part of the coastal temperate rainforest ecosystem typical of coastal British Columbia, with deviations from the expected ecology attributable to the extent of forest harvest, and the accompanying shifts in nutrient cycling, temperature regimes, and flow rates resulting from logging.

The streams of Pacific Rim NPR provide habitat for a variety of vertebrate and invertebrate organisms. Most faunal studies in this region have focussed on vertebrates, specifically fish (Rosenfeld *et al.* 2000) and amphibians (Suski *et al.* 1998), leaving the diversity of invertebrates relatively unknown. The only work done on benthic macroinvertebrates in the Pacific Rim NPR area to date focussed on headwater streams, and was carried out by the Long Beach Model Forest Society (Suski *et al.* 1998). The benthic macroinvertebrate fauna collected from creeks in this study are dominated by insect larvae, along with amphipods, annelids, bivalve and gastropod molluscs, crustaceans, and an abundance of mites. Most of the insects collected belong to the ephemeroptera, plecoptera, trichoptera, and diptera, groups which are generally well studied because of their abundance and relatively large size.

The ephemeroptera, commonly called mayflies, are an attractive group with a variety of adaptations for living on the exposed surfaces of the stream bottom, and in the moving water of the stream. Commonly collected mayflies in Pacific Rim NPR include the streamlined, clinging *Cinygma, Epeorus* and *Cinygmula* species as well as the free swimming *Baetis* spp. Plecopterans, or stoneflies, are typically found in the spaces between rocks and gravel substrate. Stoneflies tend to have robust bodies and legs for crawling through substrates, with elaborate gills for obtaining sufficient oxygen from interstitial water. Commonly collected taxa in Pacific Rim NPR include *Skwala* and *Sweltsa* species, and the small, hairy *Zapada* species. Trichoptera, or caddisflies, are a fascinating group, as many caddisflies create "houses" for themselves from their own silk and specific benthic materials. Commonly collected trichopterans in Pacific Rim NPR include the free-living *Rhyacophila* species, and the small pebble-house building *Glossosoma* species. Diptera, the true flies, are generally more tolerant of fine sediment loading and other stressors of stream ecological integrity, because they are adapted for burrowing or fastening themselves in place. Many campers are far too familiar with the most commonly collected dipteran - *Simulium* species ... the black flies. A variety of interesting crane fly larvae (Family Tipulidae), typically adapted for burrowing through fine sediment, were also collected.

Pacific Rim National Park Reserve is perceived to be one of Canada's most ecologically stressed National Parks, reporting 19 of 29 ecological stressors listed in the State of the Parks 1997 Report (Parks Canada 1997). Inadequate attention to ecological integrity during Park establishment and past management has forced current managers of Pacific Rim NPR, and indeed most of Canada's National Parks, to take a remedial approach to ecological integrity. This is reflected in a legislated mandate for ecosystem-based management. While new Park establishment has the potential to capture intact ecological systems, managers of established Parks have chosen to adopt a program of measurement, action, and feedback to deal with stressors, while building understanding about ecosystem function (Ecosystem Management Task Force 1992; Parks Canada 1994a).

Though ecosystem-based management has been identified as a framework to achieve the ecological integrity mandate, the task is particularly difficult in Pacific Rim because the Park includes few complete watersheds. The Nitinat Lake watershed is an exception, lying almost entirely within the Park, yet historical logging and townsite development prevent this watershed from being considered "pristine". Encroachment by incompatible land uses was identified as the largest single threat to western National Parks over a decade ago (Zinkan, *et al.* 1990) and increasingly intense human use of some resources stresses ecosystems from within parks (Parks Canada 1997). Therefore, improved understanding of the cumulative effects of external and internal stressors on Pacific Rim is a prerequisite for ecosystem-based management.

Many coastal streams flow from adjacent lands, through terrestrial areas of the park and into marine receiving waters, illustrated in figure 1. The role of streams in transporting everything from nutrients to contaminants, downstream and upstream in the case of anadromous fish and tidal action, makes them highly interconnected ecosystem components and potential vectors of ecological stress. Attempting to manage ecological integrity in streams that cross management boundaries provides the additional challenge of developing co-operative relationships with managers of lands adjacent to Pacific Rim.

An important objective for this project is to provide scientific support for management options inside and outside the park that enhance ecological integrity. Several studies have been conducted on streams of the West Coast of Vancouver Island (Rosenfeld 1998; Rosenfeld *et al.* 2000; Toews and Moore 1982). These previous studies have focussed on fish and critical fish habitat, such as large woody debris. While these studies provide some baseline information on the area, their emphasis on salmonids limits their usefulness in discussions of ecological integrity at ecosystem scales.

Increasingly, parks are considered in the context of their social, economic and environmental surroundings, and important partnerships with outside individuals and organisations are becoming commonplace. Yet there is still a lot of progress to be made in placing National Parks at the core of a holistic national, even global, system of sustainability. The UNESCO Man in the Biosphere Reserve designation has been applied to Clayoquot Sound, in which the Long Beach Unit of Pacific Rim NPR is located, along with two other Canadian regions containing National Parks. The Biosphere Reserve designation attempts to recognise this potential role for parks to be the "core protected area", surrounded by a "zone of cooperation" where development is limited to activities that do not threaten the park's integrity, in a larger matrix of urban and rural environments managed for sustainable development of economic, social and environmental needs. In Canada, the Biosphere Reserve designation is not legislated, it serves merely as a banner to encourage a holistic approach. The Biosphere Reserve designation, like the park at its core, can be a tool for sustainability, protecting ecosystems, economic development, and quality of life. However, the whole process requires sufficient buy-in from local interests. As in so many other cases, success on the path to sustainability relies on local and regional progress with a global vision.

2.2 Macroinvertebrate Sampling

Fieldwork for the B-IBI was completed over three weeks in August and September of 2001. Methods typical of IBI application across North America were used (Carter and Resh 2001), with some fine-tuning appropriate to the Pacific Northwest (Karr and Chu 1999). Ideally, all habitats within a stream would be sampled in order to best represent the full diversity of macroinvertebrate taxa. In practice, some streamlining of the sampling process was required in order to ensure efficiency and consistency. Samples were collected from the "richest targeted habitat" (RTH), a fast flowing, coarse grained riffle (Cuffney *et al.* 1993). The concept of optimizing sampling effort by targeting habitats with high macroinvertebrate diversity is supported by several papers and a general consensus exists that riffles constitute the best habitat for macroinvertebrate sampling (Karr and Chu 1999; Hewlett 2000).

Pools contain macroinvertebrate assemblages that are heterogeneously distributed and less diverse than riffles (Mermillod-Blondin *et al.* 2000). Though they are less thoroughly researched, there may be merit in including pools in sampling protocols because they are also influenced by human impacts on stream integrity, possibly even more so than riffle assemblages when sedimentation is a stressor. Some sampling protocols have included all available habitats, suggesting a mix of methods and decidedly non-random picking of individual organisms from riffles, glides, pools, woody debris and coarse particulate organic matter (Karr and Chu 1999). Despite the potential value of such comprehensive sampling approaches, expedience and the choices of many researchers in the region (Reynoldson and Rosenberg 1998; Karr and Chu 1999; Fore *et al.* 2001; Morley and Karr 2002) supported sampling from coarse grained riffles –to simplify the task and improve consistency and comparability among sample sites.

Macroinvertebrates were collected from shallow riffles in each study stream with a 373 micron mesh Surber Sampler. The Surber sampler consists of a pair of square metal frames (0.3 x 0.3m) locked at right angles. One of the frames has a fine mesh net attached. When the sampler is placed on the creek bed, the bottom frame delineates a 0.1m^2 area of benthic habitat, and the upright frame holds the net open, immediately downstream of the benthic habitat to be sampled. Riffles of about 5 – 20cm depth, with 3 – 15cm cobble, were selected to maximize the expected diversity of benthic invertebrates. The Surber sampler was placed in the water, large cobbles were picked up and thoroughly inspected, wiped and rinsed, then gravel and sand in the Surber frame was thoroughly scrubbed, stirred and agitated to a depth of approximately 10cm. Neoprene gloves were worn to allow sufficient scrubbing of all bed material, and the same operator completed all substrate-scrubbing, to ensure consistent sampling effort.

Macroinvertebrate material was either placed into the sorting basin by hand, washed into the Surber sampler by stream current, or subsequently rinsed from the Surber sampler into the sorting basin using a bottle of stream water.

Invertebrates were separated from sand, gravel and detritus by eye, using fingers, forceps and eyedroppers to remove them from the white plastic sorting basin. Organisms were placed into vials of 95% ethanol, and then topped up with creek water to about 70% ethanol after the "picking" of macroinvertebrates was complete. Three samples were collected from each study site, from different locations in the same riffle, or from adjacent riffles, depending on the size and proximity of riffles in the study stream. Consecutive samples were completed from downstream to upstream, so as not to influence subsequent sample sites.

Some methodological choices were dictated by the remote nature and foot-only access to the sites. Macroinvertebrates were removed from samples by hand in the field, as opposed to laboratory separation of organisms from detritus under the microscope. This allowed smaller sample vials to be used, and protected sample quality by minimizing the decay and physical damage that inclusion of detritus and gravel would have caused during the 1-9 day hike out with the samples. Field picking also allowed organisms to be counted, ensuring that samples contained a sufficient number of organisms. Some small, inactive individuals may have been missed by this approach, but organism counts per sample were comparable to test samples collected earlier in the summer and picked under a microscope. In retrospect, field picking may have missed some organisms with cases made of sand, such as certain chironomids and trichoperans, because they would behave much like the sand that would also be captured in the Surber sampler. Li and colleagues (2001) found that Surber samples from coastal and Cascades streams in Oregon collected four to eight new taxa with each of the first four samples. Li and colleagues (2001) found an average of 12 to 24 taxa per creek from three samples. This is very similar to the range of my samples, where three Surber samples per creek yielded 13 to 23 taxa, not including Camper Creek with only 9 taxa.

Laboratory processing of samples entailed sorting, identifying and storing all collected macroinvertebrate specimens. Though subsampling of as few as 100 organisms is commonly done (Carter and Resh 2001), subsampling has been show to reduce the effectiveness of macroinvertebrate biomonitoring (Doberstein *et al.* 2000; Karr and Chu 1999). Therefore, all individuals were counted and identified under a dissecting microscope using published keys (Merritt and Cummins 1996; Thorp and Covich 2001). For the Ephemeroptera, Plecoptera, Trichoptera and the majority of other insect taxa this meant identification to genus, with identification to family for chironomids and "legless" taxa. In total 3536 individuals from 64 taxa were examined. Photographs of each taxon were produced to aid in confirming identifications and to allow for future development of a pictorial key to the macroinvertebrate taxa of Pacific Rim NPR.

The methodology employed in this study was influenced by the most comprehensive guide to B-IBI methodology available during the planning of the study in 2000, *Restoring life in running waters: Better biological monitoring* (Karr and Chu 1999). Karr and Chu (1999) evaluated the IBI literature and filled gaps with experiments and analyses of their own in order to recommend the methods best suited to the Pacific Northwest.

2.3 Environmental Data Collection

Descriptive information was collected for each study site included in the project. The types of data collected were identical for sites in the Long Beach unit (LBU) and the West Coast Trail unit (WCTU) of Pacific Rim NPR, though some slight modification of measurement technique was required for weight and power constraints of the WCTU. Descriptive data were collected in order to assess the ecological similarity of study sites. Measurements focussed on highly variable features such as creek flow velocity and weather conditions, and temporally more stable features such as bank-full width and riparian vegetation. The author and an assistant typically gathered the data, though all variables could be assessed by a single operator with a laser range finder and some ingenuity. Two fieldworkers were preferred for the ability to "multi-task" and the decreased likelihood of interference from wildlife.

Study site location was determined with the Garmin Etrex Vista handheld GPS. The GPS gave reasonable data beneath all but the densest forest canopy, and provided coordinates with a self-determined error of 6 – 30m. The resulting map (Fig. 2) shows that study sites corresponded with the intended creeks, and allowed visual comparison of relative locations of study sites. The GPS unit also calculated the elevation of each waypoint through a combination of satellite signals and barometric pressure. All study sites were below 100 meters above sea level, including an error of up to 30m.

The rate and volume of water flow in creeks has considerable effects on the benthic macroinvertebrate community (Rempel *et al.* 1999). Creek discharge was calculated to assess relative differences among sample sites. The average cross sectional profile and current velocity were measured with basic techniques for each study site, using a folding rule and laser rangefinder or tape-measure for distance measures, and a cork and stopwatch for current velocity. Use of a positively buoyant object is a very rudimentary way to gauge current velocity, as the surface current is typically faster than the average current from all depths (Brooks *et al.* 1997). However, field testing of "floater" objects showed that the small, positively buoyant wine cork was least likely to become caught on the substrate of the shallow riffles, compared to traditional hydrological implements such as an orange. Ideally, an electronic current meter would be employed to measure velocity at a range of depths across the measured cross section of stream, but a suitably robust yet affordable current meter was not available for the field season. The bank-full width was also recorded, to permit estimation of peak discharge. An estimate for stream discharge at the time of sampling was calculated by Q=VA, where Q is discharge (m^3/sec), V is velocity (m/sec) and A is cross sectional area (m^2) (Brooks *et al.* 1997).

The geomorphologic characteristics of each study catchment were assessed through a combination of field observation, digital analysis in ArcView, and visual observation of maps, spatial data, and satellite imagery. Strahler stream order was determined visually for each creek, from digital TRIM stream data layers at 1:50 000 scale (Strahler 1957). Catchment areas were determined digitally with ArcView. Substrate size was measured for each macroinvertebrate sample, and substrate size values averaged for use in statistical analyses. Gradient was measured at each study site using laser range finder or clinometer and tape measure. Stream gradient was typically measured over a 10m reach, centred on the sample site. Water temperature was measured with a thermometer, hung at roughly half depth, near to the Surber sample locations.

In general, biogeoclimatic classifications have not been found to correlate well with benthic macroinvertebrate assemblages (Gerritsen *et al.* 2000; Hawkins and Vinson 2000; Sandin and Johnson 2000; Waite *et al.* 2000), though invertebrate assemblages have been found to coincide well with ecoregions that have been designated based on aquatic vertebrates (Rabeni and Doisy 2000). The only ecoregions that have been designated in Pacific Rim National Park Reserve are based primarily on geology, soil and plant communities (Green and Klinka 1994). All study sites occur in the same biogeoclimatic zone, though further classification to site series was not carried out.

As an indicator of riparian condition, and because of the relevance of sunlight exposure to primary productivity, canopy closure over the sample reach of each stream was assessed by taking a photo directly overhead of the sample site, looking straight up. These photos were compared, and each one given a score for percentage closure, in increments of 10%. Visual inspection of the photos with a transparent grid overlay allowed consistent "eyeball" appraisal of the canopy closure. A key assumption of the IBI is that the creek integrates effects from the entire watershed. The site series classification of the area immediately surrounding each study site is only part of the habitat affecting the macroinvertebrate assemblage at that point. Rather, the ecological description of the entire watershed (the biogeoclimatic zone and variant) is a more appropriate indicator of overall watershed ecology, and is assumed to contribute as much information as possible about the comparability of the macroinvertebrate assemblages. This pattern is evident in the American Midwest, where regional land use is the primary determinant of stream conditions, overwhelming the ability of local site vegetation to support high biotic integrity (Roth *et al.* 1996).

2.4 Assessing Human Impact

Calibration of the B-IBI requires quantitative evaluation of ecological disturbance in each study watershed, in order to ensure that the study sites encompass a gradient of human impact. LANDSAT-7 TM satellite imagery provides multi-spectral coverage of the study area with 30x30m pixel resolution. Imagery collected in August 1999 (WCTU) and August 2000 (LBU) was obtained from the Western Canada Service Centre (Vancouver) of Parks Canada. Watershed data were obtained from the BC Watershed Atlas in ArcView shapefile format, available online (MSRM and MWLAP 2002). Watersheds of streams that are 3rd order or smaller were lumped together by the Watershed Atlas, so study streams smaller than 3rd order were manually separated and redrawn using topographic data. Most watersheds in LBU were manually drawn in this fashion, because the atlas lacked sufficient detail of watersheds in the relatively flat area adjacent to LBU.

Land use patterns in and adjacent to Pacific Rim are relatively simple; most areas can be clearly identified as intact forest or regenerating patches of forest that have been disturbed. Commercial forestry began about half a century ago (Forward 1979) and continues at present, therefore areas of second growth forest in the study area range from over 50 to less than 1 years old. Exact determination of stand age was not important for this project, as the real objective was to identify disturbance capable of affecting ecological integrity in each catchment. The satellite image interpretation methods described below were intended to identify patches that were sufficiently disturbed at the time of the study to impair the ecological integrity of streams in the corresponding catchment.

Analysis of LANDSAT-7 ETM imagery by various approaches yielded slightly different disturbance rankings for the study watersheds, suggesting that the assessment is sensitive to the analytical approach used. Without a properly structured experiment to determine the hydrologic impact of forestry patterns in my study watersheds, it has been assumed that hydrologic impacts at the study sites are typical of impacts noted in other studies of forestry impacts, with changes to flow and nutrient regimes persisting for at least 20 years after harvest (Thomas and Megahan 1998; Canadian Council of Forest Ministers 1997), and some flow effects persisting for 50 or more years after harvest (Harden and Mathews 2000; Jones and Grant 1996). Based on review of relevant literature (Morley and Karr 2002; Smith *et al.* 2000; Wente 2000; Rapport *et al.* 1998; Roth *et al.* 1996), and experimentation with different analytical methods, an unsupervised classification and subsequent interpretation of the resulting classes into different "impact classes" was an efficient and effective choice.

An unsupervised ISODATA clustering classification of LANDSAT-7 ETM images provided the simplest means of distinguishing disturbed areas from intact forest (figures 2 and 3). Classification accuracy was qualitatively verified by comparison with forest cover maps from forest development plans (FDPs). FDP data polygons are derived from aerial photographs and reviewed by the British Columbia Forest Service. Dorner and colleagues (2002) used a combination of satellite image data and aerial photographs to map forest disturbances in mainland British Columbia forests, and found that differences in topographic features among study sites introduced differences in landscape classification. The Long Beach Unit and West Coast Trail Units of the Park were analyzed and verified separately, but more sophisticated digital elevation model (DEM) based correction of topographic effects, as conducted by Dorner (2002), was not applied to this study. ISODATA (Iterative Self-Organizing Data Analysis technique) was used to categorize the multiband continuous data of the LANDSAT images into a single layer raster data theme. ISODATA is an iterative technique that makes several passes through the data to categorize it into unique classes, recalculating the statistics of each class with each iteration until the classes reach a specified threshold of convergence. Data that have similar spectral characteristics will be grouped into the same class (ArcView Image Analysis on-line help Copyright (c) 1998 ERDAS, Inc.) The number of classes was set to five.

Each class designated by the unsupervised classification was labeled from 1 to 5. When the ISODATA classification output was compared with a Forest Development Plan forest age map layer, clearcuts harvested approximately 0-10 years ago corresponded with class 5, and clearcuts harvested approximately 10-20 years ago corresponded with class 4. Classes 1-3 corresponded with older forest and other features. The Forest Development Plan data was obtained from Pacific Rim NPR, through a memorandum of understanding with Weyerhaeuser Company.

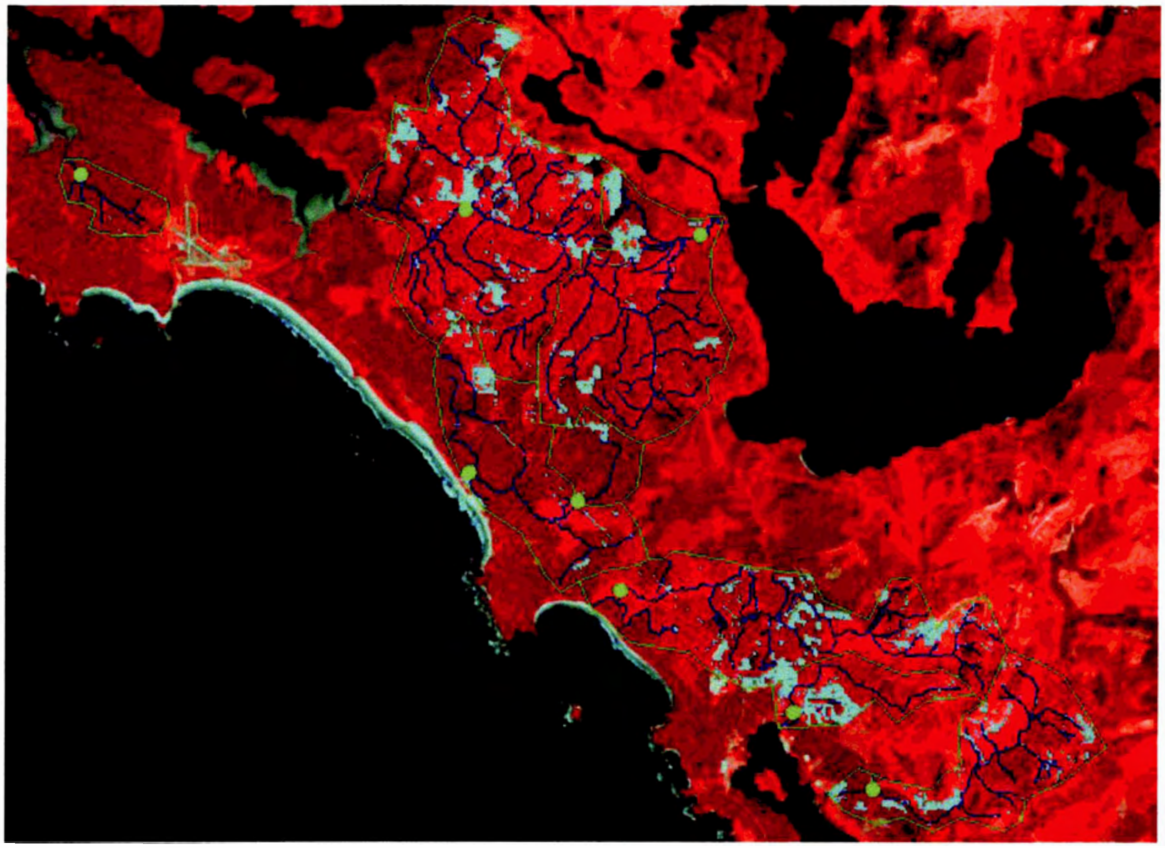

Figure 2. False colour infrared LANDSAT-7 ETM image of Long Beach Unit, Pacific Rim NPR, showing study sites (green points), creeks, and watersheds. Light blue patches are disturbed, according to the 00005 impact scoring method. ©Baron, 2003.

Since the unsupervised classes 4 and 5 corresponded well with recently logged areas, two methods for assigning impact scores to watersheds were analysed. The first scoring method considered only class 5 areas as sufficiently disturbed to impact stream integrity in the watershed, and was labeled 00005. Scoring methods were labeled based on the scores assigned to each class, so the label 00005 refers to scores of 0 for classes 1-4, and a score of 5 (impacted) for class 5. The second scoring method considered class 4 and 5 as sufficiently disturbed to impact stream integrity in the watershed, and was labeled 00055. Many other scoring approaches were explored, including score code 12345 where all classes contributed to the impact score, weighted according to class, and score code 00555, where the first two classes (which correspond roughly with intact old growth forest) do not contribute to the disturbance score, but each of classes 3,4, and 5 are considered maximally impacted. Usage of score codes 00055 and 00005 for the satellite images in this study is based on certain assumptions about the rate of hydrological recovery for the study watersheds, following logging. It has been asserted by forest industry organizations that the impacts of forest disturbance on stream integrity are most significant during the first 3-5 years following logging, and impacts to stream hydrology will decrease over time but require up to 10 to 20 years (Thomas and Megahan 1998; Canadian Council of Forest Ministers 1997), to more than 50 years (Jones and Grant 1996) after completion of logging to return to pre-disturbance conditions. Other authors have re-analyzed the same data as Jones and Grant (1996) and determined that peak flow events are affected to a much lesser degree, and only in small catchments (Beschta *et al.* 2000). Other studies have shown that sediment inputs to creeks may return to pre-harvest levels within 20 years after logging, but surface water retention and runoff that is characteristic of well developed organic soil layers may take longer than 50 years to return to pre-harvest rates following logging (Harden and Mathews 2000).

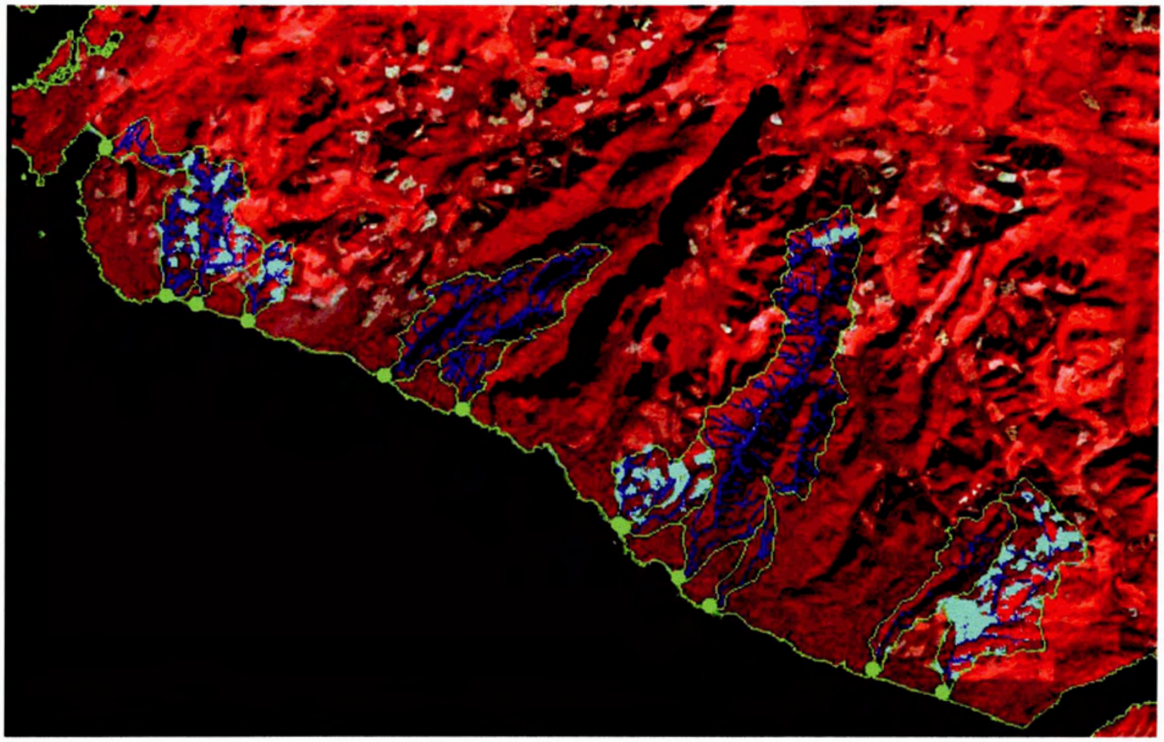

Figure 3. False colour infrared LANDSAT-7 ETM image of West Coast Trail Unit, Pacific Rim NPR, showing study sites (green points), creeks, and watersheds. Light blue patches are disturbed, according to the 00005 impact scoring method. ©Baron, 2003.

Every 30x30m pixel of the classified image, within each study catchment, was assigned a score according to one of the codes described above. Overall catchment impact scores were determined by calculating the mean pixel score within each catchment using the "summarize zones" function of the ArcView Image Analysis software. Impact scores for each catchment were translated to "% disturbed area" by division of the mean pixel score by 5 and multiplication by 100.

2.5 Metric selection and calibration of B-IBI

Candidate metrics are selected based on knowledge of aquatic systems, flora and fauna, literature reviews, and historical data (Barbour *et al.* 1995). A list of candidate metrics was compiled from the relevant literature, and each metric calculated from the taxa data. Ten multiregional metrics, listed in table 2, have been suggested for the Pacific Northwest (Karr and Chu 1999). In general, metrics involving the Ephemeroptera, Plecoptera and Trichoptera taxa (EPT) have been shown to correlate well with stream impacts (Smith, *et al.* 2000; Baker and Sharp 1998). In a study carried out in the Fraser River catchment in British Columbia, metrics based on taxonomic richness were found to be the most useful of all types of metrics in distinguishing between impaired and unimpaired streams, a pattern which is consistent among similar studies (Resh *et al.* 2000). The three core metrics that consistently respond to stressors in any environment are taxa richness, relative abundance of tolerant (generalist) individuals, and number of sensitive or intolerant taxa (Karr and Chu 1999).

Table 2. A list of metrics that have performed well in multiple regions.

Metric	**Predicted response to increased impact**
Taxa richness and composition	
Total number of taxa	Decrease
Ephemeroptera taxa	Decrease
Plecoptera taxa	Decrease
Trichoptera taxa	Decrease
Long-lived taxa	Decrease
Tolerants and intolerants	
Intolerant taxa	Decrease
% tolerant	Increase
Feeding and other habits	
% predators	Decrease
"Clinger" taxa richness	Decrease
Population attributes	
% dominance (top three taxa)	Increase

Diversity indices should not be included, because they combine richness and relative abundances (Karr and Chu 1999). Instead, richness and relative abundance should be considered individually, because changes in both may not be apparent when they are combined. In addition, diversity indices are correlated with several metrics already under consideration, such as number of taxa, and percent dominant taxa (Barbour *et al.* 1996). For the above reasons, diversity indices were not included in this study.

Sensitive taxa were determined through a literature review. *Ameletus* and *Paraleptophlebia* genera have been shown to be sensitive to metals in mesocosm experiments in coastal BC (Richardson and Kiffney 2000). However, densities of *Paraleptophlebia* spp have been found to increase immediately after anthropogenic disturbance resulting in increased inputs of fine sediment (Relyea *et al.* 2000). For this reason, stressor specific metrics were calculated for metal contamination and fine sediment loading. The metal contamination metric was calculated by summing the taxa richness of *Ameletus* and *Paraleptophlebia*, however this metric did not prove to be robust enough for use. Heavy metal contamination is not suspected in any of the creeks examined in this study. The military history of the Tofino Airport site indicates the potential for metal contamination from dumping of wastes during and after World War II (Pellerin 1995). Creeks around the Tofino Landfill may also be at risk of metal contamination from surface and subsurface leachate (Bob Redhead, Pacific Rim NPR Biologist, personal communication), therefore the use of an *Ameletus* and *Paraleptophlebia* richness metric would be appropriate in future studies focussing on creeks adjacent to the airport or landfill sites.

The impact of sediment loading was assessed with two metrics, one for tolerant taxa and one for intolerant taxa. The sediment tolerant taxa include *Baetis*, *Paraleptophlebia*, and Chironomidae, and the intolerant taxa include two plecopterans: *Kathroperla, Zapada*, and the ephemeropteran *Cinygmula* (Relyea *et al.* 2000).

Tolerance metrics are expressed as percentages of total abundance, and intolerance metrics as taxa richness, to best account for the relative lack of abundance of intolerant taxa (Fore *et al.* 1996).

Long lived taxa where identified from a summary of insect life histories (Merritt and Cummins 1996). Life span information was not available for all taxa identified in this study. The majority of taxa for which information is available complete one or more generations annually. Semivoltine and merovoltine taxa – those that require two or more years per generation – were considered long-lived. This includes *Claassenia*, one of two possible *Zapada* spp., *Sweltsa*, and one possible *Rhyacophila* sp. The study streams were assumed to have variable but perennial flow, so the presence of long-lived taxa could be limited by flash flooding and scouring events. Many factors affect stormflow response, but in general steep, rocky catchments tend to be "flashy", having high peak flow events of quick onset and short duration (Brooks *et al.* 1997). Forest harvest has been shown to increase the volume of peak flows in harvested catchments (Storck *et al.* 1998). If the relative abundance of long-lived taxa is inversely related to flash flood potential, then lower abundances would be expected from steep West Coast Trail Unit creeks, and lowest abundances from highly impacted WCTU creeks (Fig 3).

2.6 Statistical Analysis

2.6.1 Multimetric Index

The statistical properties of a multimetric IBI have been examined by other authors using resampling simulations, and the IBI was found to distinguish among up to six categories of biotic integrity (Fore *et al.* 1994). The IBI in that study was based on diverse, abundant fish assemblages and a strong gradient of site impacts in Ohio, USA. Despite using similar design, sampling, and analytical methods, results in Pacific Rim NPR were different. Statistical evaluation of the taxa, metric, and environmental data was intended to maximize the information value of the data and evaluate statistical significance. Descriptive and exploratory statistics were calculated with SPSS (1999) to examine distributional patterns in the data, and to ensure that characteristics of the data met the assumptions required for further analysis. Creation of scatterplots between metrics and impact scores, with regression analysis of the relationship between the two, is the best statistical approach for evaluating potential metrics, because it facilitates interpretation of the ecological significance of relationships (Karr and Chu 1999). Interpretation of these analyses reveals certain limitations of this study that must be overcome for macroinvertebrate biomonitoring efforts to be worthwhile in Pacific Rim NPR.

2.6.2 Multivariate Analysis

Multivariate methods are used to identify patterns in matrices of data. Ordination refers to a set of multivariate methods which, in the simplest sense, summarize multivariate data matrices in the simpler form of a two dimensional ordination space, and in a more ambitious sense, detect the influence of underlying gradients on multivariate data (ter Braak 1995). Both services are useful in this project, to simplify representation of the variety of taxa and environmental variables present at each study site, and to identify and isolate the effect of environmental variables on macroinvertebrate taxa in order to assess the relationship between human disturbance and ecological structure in the creeks of Pacific Rim NPR.

Various multivariate analyses are useful for biological monitoring, including principle components analysis (PCA), redundancy analysis (RDA), correspondence analysis (CA), canonical correspondence analysis (CCA), non-metric multidimensional scaling (NMDS) and cluster analysis (Downes *et al.* 2002). The most appropriate method is determined by the characteristics of the data under analysis. Patterns in the data were explored through systematic application of each of these methods, to determine the strength of those patterns under various assumptions. PCA and RDA assume a linear relationship between the abundance of taxa and underlying gradients, though in many cases taxa have a unimodal relationship with underlying environmental gradients, requiring CA or CCA. Because sites were sampled over a relatively small area with limited impacts, the gradients underlying my data are likely short enough that the relationships appear to be linear. Gradient lengths were evaluated by running DCA on the data and inspecting the gradient lengths in the CANOCO log file. Since the longest gradient was approximately equal to four times the standard deviation of the first axis, this data falls on the cusp between linear and unimodal models (ter Braak and Smilauer 1998). For this reason, both linear and unimodal analyses were run, and all results compared.

Macroinvertebrate abundance data, like most ecological variables, are rarely structured in such a way as to meet all the requirements for desired statistical analyses. In order to address some of these assumptions, data may be transformed and cases or variables may be downweighted or omitted. One of the criticisms levelled at the application of multivariate methods to biomonitoring data is the frequent requirement for exclusion of "outlying" sites or variables in order to perform a meaningful analysis (Karr and Chu 1999). Exclusion of rare taxa has the potential to lose ecologically relevant information, however the exclusion of one site and two macroinvertebrate taxa from my study is easily justified for ecological reasons, and benefited my analyses as described below. Omitted taxa were still able to be included in the analysis as passive samples, to see where they fall on the ordination axes without letting them influence the analysis.

Transformations are generally of two types, those intended to make data with different units comparable (for example, my temperature and catchment area environmental variables), and those intended to improve the fit of abundance data with statistical regression models (Jager and Looman 1995). Square root and logarithmic transformations are offered in Canoco (ter Braak and Smilauer 1998), the software used for multivariate analyses. Both transformations are intended to adjust the distribution of abundances, preventing highly abundant taxa from having too much influence on the ordination. In my dataset a few of the uncommon taxa show a Poisson distribution, with variance roughly equal to the mean, however variance exceeds the mean for all other taxa, indicating an aggregated distribution (Jager and Looman 1995). Either a square root or logarithmic transformation could improve the analysis by limiting the potential for very common taxa to overshadow less common taxa. The logarithmic transformation would be problematic, because my macroinvertebrate data matrix contains many zeros – taxa absent from a given creek. The log of zero is infinity, which is difficult for computers to process in a timely fashion. To work around this, Canoco allows adjustment of all data values by addition of a specified small, non-zero amount. Though this feature enabled me to use the logarithmic transformation, it is probably not valid, because none of the abundance data showed a log-normal distribution. The effectiveness of plausible transformations was assessed by comparing their impact on the statistical significance of the ordination axes with the significance of ordinations with untransformed data (Fore, Karr, and Wisseman 1996). Compared to untransformed data, there was no improvement in explanatory strength or significance of ordination results with logarithmic or square root transformations.

Data from Camper Creek in the WCTU were excluded from some analyses, because only 25 individual macroinvertebrates were collected. A significant rainstorm occurred the night before Camper Creek was sampled, and the dramatic rise in water level prevented sampling from occurring in a manner consistent with other creeks. Many macroinvertebrates use the shore zone as a refuge during flooding (Rempel *et al.* 1999), but the expected diversity and abundance of macroinvertebrates where not present in the Surber samples from Camper Creek, suggesting that some taxa sought refuge further from shore, deeper in the hyporheic zone, or were dislodged and washed downstream. The only taxa unique to Camper Creek were several collembolans. The absence of Collembola in samples from other creeks suggests that heavy rains and high water levels may be responsible for dislodging them from their usual habitat of soil, litter and moist vegetation (Merritt and Cummins 1996) onto the surface film of Camper Creek, and into the Surber sampler. The decision to exclude data from Camper Creek is regrettable, because the low diversity, low abundance, and absence of rare taxa (other than springtails) is consistent with the ranking of Camper as the most disturbed of all study watersheds. Inclusion of Camper in multimetric analyses increased the correlation between many metrics and impact scores, yet inclusion of Camper in multivariate analyses overwhelms the scale of the ordination axes and masks the relationships between all other sites. Increased peak flow events are consistent with the expected effects of extensive, recent forest harvest in the Camper Creek watershed (Brooks *et al.* 1997). Though statistical arguments would suggest exclusion of Camper, ecological explanations support its inclusion.

3. Results

Macroinvertebrate samples were collected from 19 creeks, yielding 3536 individuals from 64 taxa. The mean for all creeks was 185 individuals from 16 taxa. All ephemeroptera, plecoptera, and trichoptera were identified to genus, along with all other insect taxa except chironomids (Merritt and Cummins 1996). All non-insect taxa were identified to less precise taxonomic resolution (Thorp and Covich 2001). All samples have been preserved in ethanol, and retained at Parks Canada's Western Canada Service Centre in Vancouver, British Columbia. Photographs of all taxa were created, and will be compiled into a pictorial list of the macroinvertebrate fauna of Pacific Rim NPR.

3.1 Benthic Index of Biotic Integrity

In general, the relationships between metrics and impact scores were as expected (Tables 2 and 3, based on Karr and Chu 1997). The strength of correlation between metrics and impact scores varied, but was generally low. Table 3 shows the performance of the ten regionally strong metrics identified in table 2. Table 3 contains R^2 values for correlations between the each metric and impact scores that considered areas logged within approximately the last decade as "impacted" (coded as 00005) and impact scores that considered areas logged within approximately the last 20 years as "impacted" (coded as 00055). This coding system was described in more detail in section 2.3, above. All metrics showed a stronger correlation with 00005 impact scores than with 00055 impact scores, with the exception of the metal intolerant taxa and percent predators metrics, which showed stronger correlation with the 00055 impact scores. This could indicate that the presence of metal intolerant taxa and relative abundance of predators is related more to disturbances that have occurred over the last 20 years, than to recent disturbances.

Table 3. The predicted and actual response of regionally appropriate metrics to increased impact scores, along with the R^2 value of the regression between each metric and 00005 or 00055 impact scores.

Metric	Predicted response	Actual Response	00005 R^2	00055 R^2
Taxa richness and composition				
Total number of taxa	Decrease	Decrease	0.227	0.010
Ephemeroptera taxa	Decrease	Decrease	0.004	0.008
Plecoptera taxa	Decrease	Decrease	0.012	0.015
Trichoptera taxa	Decrease	Decrease	0.022	0.003
Long-lived taxa	Decrease	Decrease	0.343	0.205
Tolerants and intolerants				
Sediment intolerant taxa	Decrease	Decrease	0.263	0.150
% sediment tolerant	Increase	Increase	0.065	0.006
Feeding and other habits				
% predators	Decrease	Decrease	0.024	0.421
"Clinger" taxa richness	Decrease	Decrease	0.101	0.069
Population attributes				
% dominance (top three taxa)	Increase	Increase	0.047	0.023

The agreement of predicted and observed responses for metrics listed in Table 1 suggests that they all have potential trends. The consistently weak correlations may be due to limitations of the data, oversimplification of the impact scoring system, or a small gradient of impact among study streams. Human impacts in each watershed may be complicated by variation in recovery rates after harvest, additional roads, tourism use and park facilities, instream restoration efforts, and additional unknown factors. Since none of the listed regionally appropriate metrics were flagrantly contradicted by the data, all of them were scored and included in the overall B-IBI for Pacific Rim NPR.

Some of the metrics were compared with environmental variables in order to look for expected relationships. For example, the proportion of long-lived individuals might be expected to have an inverse relationship with the propensity of a creek for extremely high flow events, as invertebrates would be "scoured out" during sudden high flows. Comparison of the proportion of long-lived individuals with stream discharge did not show any clear correlation. Stream discharge measurements were collected at the time of sampling, and so may not be closely related to the propensity of each stream to flooding.

Calculated values of individual metrics are expressed in different units and ranges, and must be normalized into unit-less scores in order to be combined into an aggregate index of biotic integrity (Karr and Chu 1999). Values for each metric are typically assigned a score of 1, 3, or 5, corresponding with increasing biotic integrity. Several methods have been employed to normalize metric scores. Where a sufficient number of undisturbed creeks may be measured to define a reference condition, interquartile ranges of metric scores for reference creeks may be used to divide each metric into three scoring ranges with values of 1, 3, and 5, each corresponding with higher biotic integrity (Barbour *et al.* 1996). This approach was not viable for Pacific Rim NPR creeks, because too few creeks were sampled to statistically define a reference condition for each park unit. There are no additional ecologically similar creeks passing through Pacific Rim NPR to define reference condition, so creeks from a larger area would need to be considered. For this study, only creeks in or near Pacific Rim NPR were chosen in order to test the effectiveness of the IBI method on a local scale.

Including creeks from a larger region, such as the entire west coast of Vancouver Island, would require substantial funding for helicopter access, as in the Fraser Basin Study described by Reynoldson and colleagues (2001).

The low-gradient nature of LBU creeks is unique on the typically steep West Coast of Vancouver Island, and comparing geographically distant creeks of a similar gradient introduces dissimilarities because of other ecological gradients related to latitude, climate, soils, or other factors. Statistical definition of reference condition through multivariate analyses would determine such dissimilarities, and attempt to compensate for them when necessary. The reference condition approach is better suited to large scale biomonitoring programs (Reynoldson and Rosenberg 1998).

Another scoring method, initially applied to richness metrics, is the Maximum Species Richness Line (MSRL) (Fausch *et al.* 1984). The MSRL approach has been refined for application with all metrics that show a linear correlation with watershed area (Liang and Menzel 1997). MSRL scoring employs a linear regression between sites' metric values and log-catchment area or stream order. The line is moved so the intercept of the regression line matches the 95% Y-intercept, but the initial slope of the regression line is maintained. This new line defines the maximum value of the metric for different sizes of watershed, so that values below the line represent impairment of varying degree. The area below the MSRL is evenly trisected with lines from the origin, and sites' metric values are given scores of 1, 3, or 5 if they fall in the bottom, middle, or top areas, respectively. This approach is not applicable with data from this study, because the uppermost values of metrics such as "total taxa" are not sufficiently linear. It is possible that the sampling effort employed in this project failed to detect some taxa in each creek.

Three Surber samples per creek were collected, based on a definitive recommendation that three Surber samples per creek was sufficient (Karr and Chu 1999). Further study in western Oregon, published after field sampling for this project was complete, demonstrated that collected taxa per stream increases rapidly with the first four to eight Surber samples (500-1000 individuals) and new taxa continue to be added after counting more than 50 samples (Li *et al.* 2001). The absence of a clear MSRL may also be due to the relatively small number of available sample sites in Pacific Rim NPR.

Since the scoring methods described above were not practical for this study, scoring ranges were derived by dividing the range of metric values into three equal score ranges (Fore *et al.* 1996), or using natural breaks and shifts in the distribution of metric values to assign scores (Karr and Chu 1999). These natural breaks in distribution are reliably determined by observing slope breaks in plots of metric ranks plotted against the same metric values (Karr and Chu 1999). The quartiles (metric values at which 25, 50 and 75% of the sites scored below that value) give an indication of skewness in the distribution of metric scores. The scoring ranges for each metric are listed in Table 4.

The ranges and quartiles listed in Table 4 are derived from all sample sites, not just reference sites as in Barbour *et al.* (1996). Whereas Barbour and colleagues (1996) used the lowest quartile of metric scores (expected to decrease with decreasing biotic integrity) from reference streams in order to set the threshold for the highest score (5), in this study the quartiles served only as a loose guide for setting scoring criteria. Scores for each metric, and overall B-IBI scores for each creek are listed in table 5. The relationship between overall B-IBI scores and the human impact scores derived from satellite image analysis is shown in figure 4.

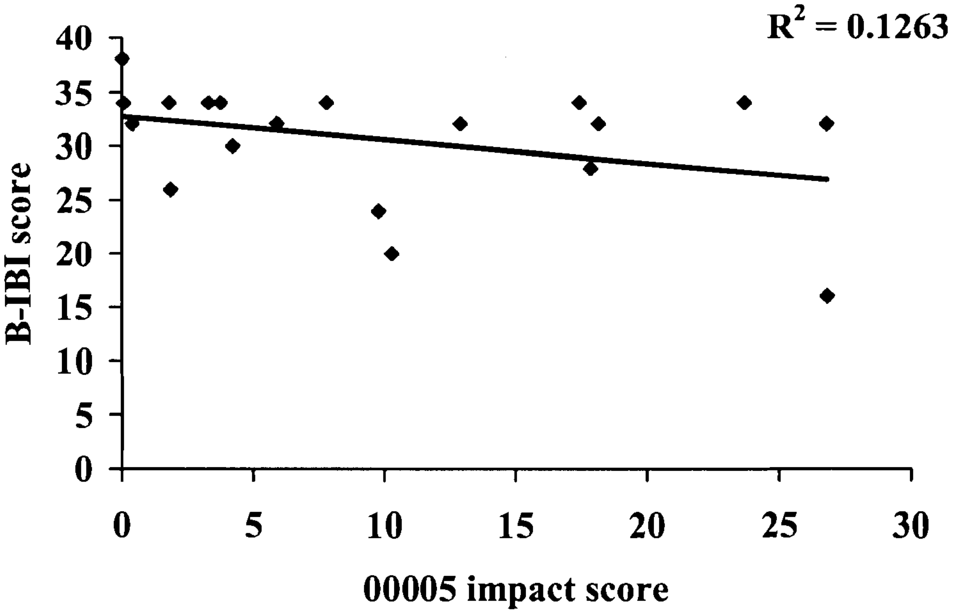

Figure 4. Scatterplot of final B-IBI scores against 00005 impact scores.

Table 4. Range, quartile statistics, and scoring ranges for metrics included in the Pacific Rim NPR B-IBI. Scoring ranges are derived from even division of metric ranges into three groups, or slope breaks in plots of metric rank vs metric.

	Statistics					**Score**		
Metric	**Min.**	**25%**	**50%**	**75%**	**Max.**	**5**	**3**	**1**
Long Beach Unit (n=8)								
Taxa richness and composition								
Total number of taxa	15	15.00	15.25	17.00	20	>18	16-18	<16
Ephemeroptera taxa	3	3.00	3.25	4.00	5	>4	3-4	<3
Plecoptera taxa	2	2.00	2.00	2.50	5	>4	2-4	<2
Trichoptera taxa	0	0.00	2.25	3.00	4	>3	2-3	<2
Long-lived taxa	1	1.00	2.00	2.50	4	>3	2-3	<=1
Tolerants and intolerants								
Sediment Intolerant taxa	1	1.00	1.25	2.00	2	3	2	0-1
% sediment tolerant	7	6.71	16.05	31.96	48	<16	16-32	>32
Feeding and other habits								
% predators	3	3.11	5.09	11.71	34	>18	5-18	<5
"Clinger" taxa richness	9	9.00	9.00	11.50	14	>14	10-14	<10
Population attributes								
% dominance (top 3 taxa)	51	50.50	54.92	57.87	72	<54	54-66	>66
West Coast Trail Unit (n=11)								
Taxa richness and composition								
Total number of taxa	9	9.80	15.00	16.00	23	>18	15-18	<15
Ephemeroptera taxa	1	1.00	2.00	5.00	6	>4	3-4	<3
Plecoptera taxa	1	1.40	3.00	4.00	7	>4	2-4	<2
Trichoptera taxa	0	0.00	1.00	1.00	3	2-3	<2	
Long-lived taxa	0	0.40	2.00	3.00	4	>3	2-3	<=1
Tolerants and intolerants								
Sediment Intolerant taxa	0	0.20	2.00	2.00	3	3	2	0-1
% sediment tolerant	19	19.96	31.84	36.26	66	<28	28-45	>45
Feeding and other habits								
% predators	0	0.60	6.09	11.38	31	>18	5-18	<5
"Clinger" taxa richness	4	4.80	11.00	11.00	17	>14	10-14	<10
Population attributes								
% dominance (top 3 taxa)	46	48.63	62.61	68.75	81	<58	58-75	>75

Table 5. Metric and overall B-IBI scores for all study watersheds in Pacific Rim NPR, with creeks ranked by total score. "Unit" refers to the section of the Park that each creek flows through, Long Beach Unit (lbu) or West Coast Trail Unit (wctu).

		Total taxa	Ephemeroptera taxa	Plecoptera taxa	Trichoptera taxa	Long-lived taxa	Sediment intolerant taxa	% sediment tolerant ind.	% predator individuals	Clinger taxa	% dominance (top 3 taxa)	B-IBI score
Creek	**Unit**	**Metric Scores**										
Kulaht	wctu	5	5	5	5	3	5	1	3	5	1	38
Sandhill	lbu	3	3	3	3	3	3	5	5	3	3	34
SH Main	lbu	5	3	3	5	3	3	3	3	3	3	34
Mercantile	lbu	3	5	5	1	3	3	5	3	3	3	34
Tsuquadra	wctu	5	1	3	5	5	1	3	3	3	5	34
Cullite	wctu	3	5	3	3	3	3	3	5	3	3	34
Tsocowis	wctu	3	5	3	3	5	3	5	1	3	3	34
Darling	wctu	3	5	3	3	3	3	5	3	3	3	34
South Bay	lbu	3	3	3	3	3	3	3	5	1	5	32
Staghorn	lbu	5	3	3	3	5	3	1	3	3	3	32
Coal	wctu	3	3	5	3	3	5	1	3	3	3	32
Michigan	wctu	3	5	5	3	3	3	3	3	3	1	32
Cribs	wctu	3	5	5	3	3	3	1	3	3	3	32
Clonard	wctu	1	1	5	3	5	3	3	5	1	3	30
Smith	lbu	5	5	3	3	3	1	1	3	3	1	28
Lost Shoe	lbu	5	3	3	3	3	3	1	1	3	1	26
Carmanah	wctu	3	3	3	3	3	3	1	3	3	1	26
Kootowis	lbu	5	3	3	3	1	1	1	1	1	1	20
Camper	wctu	1	1	1	5	1	1	1	1	1	3	16

3.2 Multivariate Analysis of Macroinvertebrate Assemblages

PCA was performed on the taxa data, with abundance values standardized to zero mean and unit variance. PCA extracts "principle components"; gradients that best explain the variation in the taxa data. The principle components are uncorrelated with each other, and the first two may be plotted as X and Y ordination axes on which sites and/or taxa may be graphed, as in Fig. 4. Comparison of the same PCA plots labelled by impact score in Fig. 4 and by location in Fig. 5 shows that the ordination axes are based more on environmental variables than impact gradient, clearly separating sites based on location in Fig. 5, but failing to group sites based on impact score in Fig. 4. This general pattern is evident in all the multivariate analyses – variation in macroinvertebrate assemblages between Park units is stronger than variation in assemblages across a gradient of human impacts. This suggests that the study creeks may not span a large gradient of impact, such that differences in macroinvertebrate assemblages are better explained by environmental variables, specifically the stream gradient and closely related size of creek-bottom substrate, than by impact rating. Alternatively, the assumption that recently logged areas, as identified by unsupervised classification of satellite images, are the most significant stressors affecting biotic integrity in the catchments may be inaccurate.

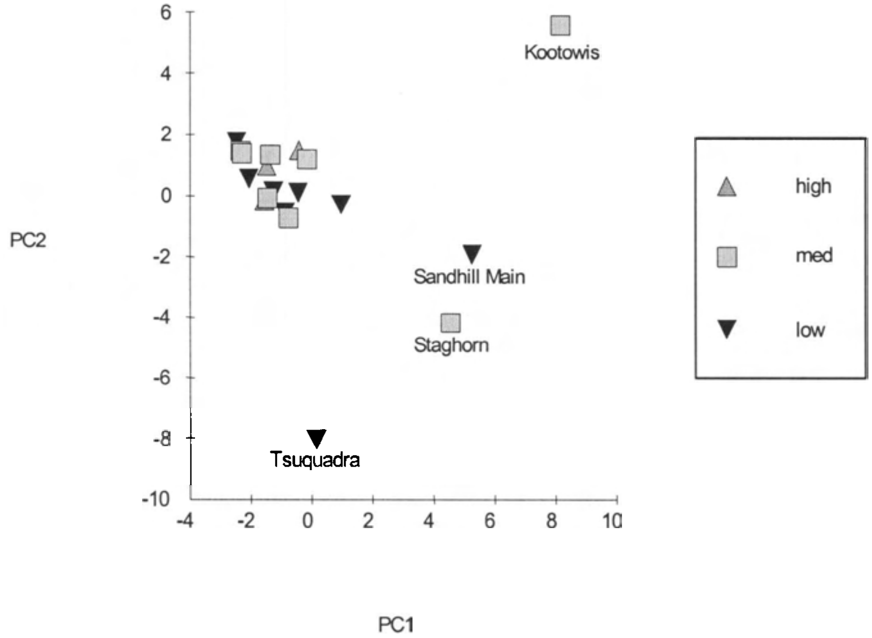

Figure 5. PCA ordination diagram of sites in Pacific Rim NPR, labelled according to 00005 impact score (low < 5%, medium 5-20%, high >20% impacted). Data were normalized and plot produced with Primer software.

Kootowis and Tsuquadra Creeks are outliers, relative to the main grouping of sites in the PCA ordination plots (Figures 5 and 6).

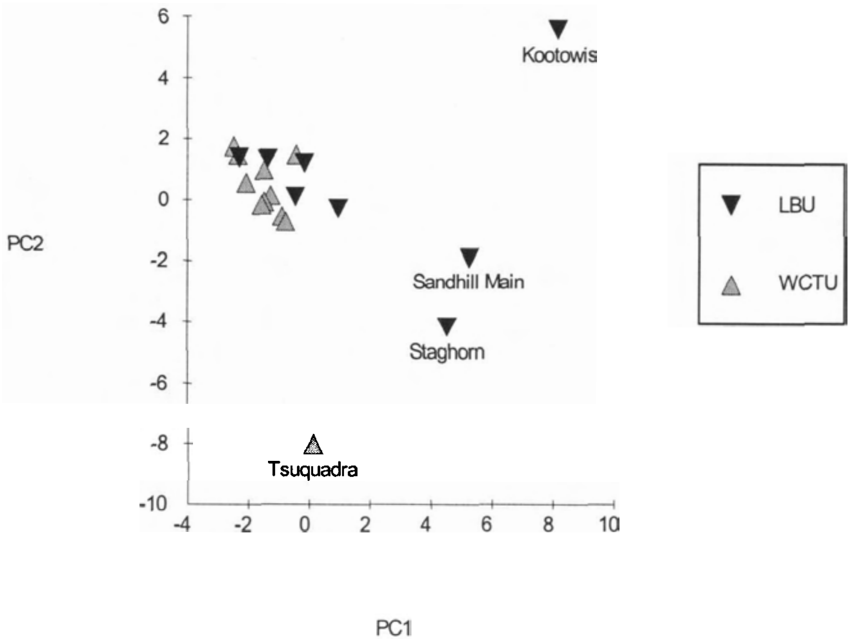

Figure 6. PCA ordination diagram of sites in Pacific Rim NPR, labelled according to location in the park's West Coast Trail Unit (WCTU) or Long Beach Unit (LBU). Data were normalized and plot produced with Primer software.

Redundancy analysis (RDA) assumes a linear relationship between taxa and underlying environmental gradients. As explained above, this assumption may be valid, as the segment lengths in this study fall on the cusp between linear and unimodal models. RDA was run on Canoco, with scaling focused on inter-sample distances, species scores divided by standard deviation, and no further data transformation. *Lepidostoma sp.* (Trichoptera) and collembola taxa were deleted, as they occurred only in Camper Creek. Manual forward selection with Monte Carlo permutation tests to assess significance of variables for inclusion in the analysis was employed, allowing evaluation of the significance of each variable's relationship with the taxa data.

Stream gradient was the only environmental variable that was significant (P=0.02), explaining 0.138 of the variance in the taxa data. The distribution of aquatic insects is largely determined by habitat selection according to substrate, flow, turbulence and other factors that affect the ability of organisms to move between or acquire patchy food resources (Merritt and Cummins 1996). Substrate, flow, and turbulence are directly influenced by stream gradient (Brooks *et al.* 1997). Thus, it is not surprising that stream gradient and related variables would be the strongest environmental determinants of macroinvertebrate assemblages.

Manual testing of the 00005 impact gradient showed it to explain only 0.06 of the macroinvertebrate variance, not a significant proportion (p=0.23). Separation of LBU and WCTU sites is evident in the resulting ordination plot (Figure 6). Gradient of the sample reach of each creek is likely correlated with the overall stream gradient, and this is supported because the variable roughly divides steep WCTU creeks from flat LBU creeks (Fig. 6).

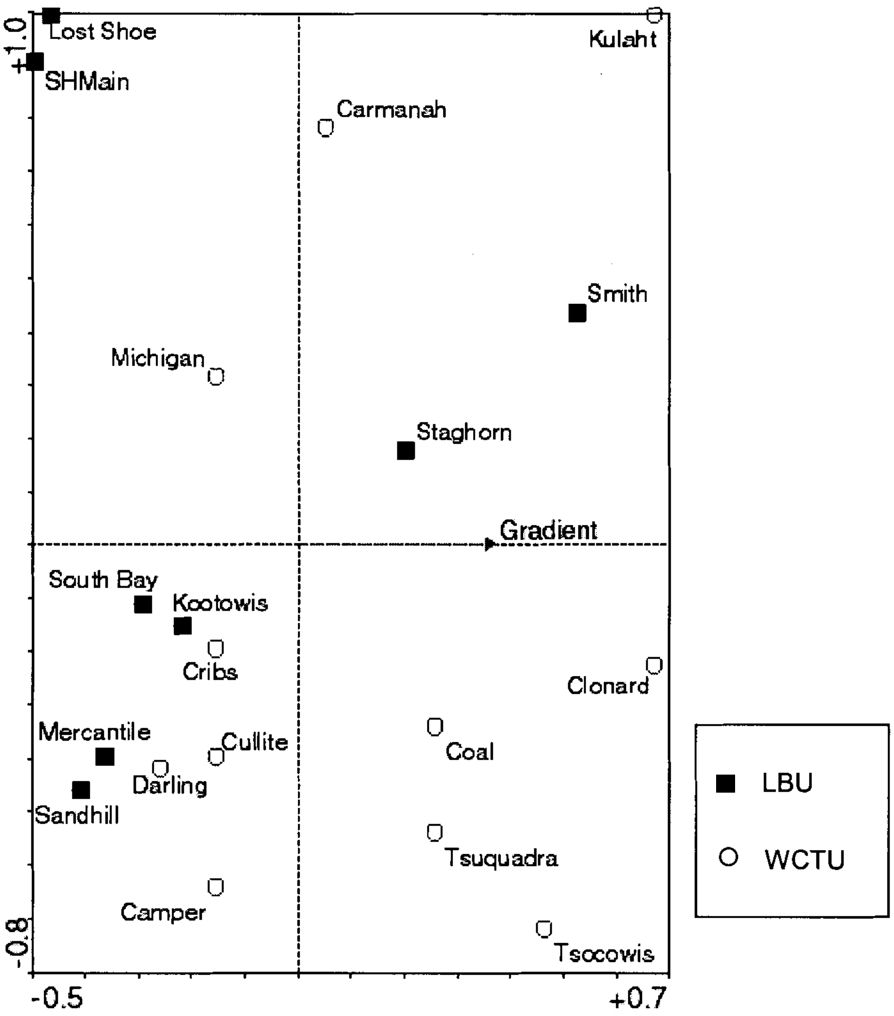

Figure 7. RDA ordination plot of sites in Pacific Rim NPR. Stream gradient at study site reach (vector labelled Gradient in plot) was the only variable shown to have a significant relationship (P=0.02) with taxa data. Ordination produced with Canoco software.

Correspondence analysis (CA) extracts the ordination axes from species data alone, maximizing the dispersion of the taxa scores on up to four uncorrelated axes (ter Braak 1995). CA is a simple multivariate method for determining the strongest patterns in the taxa data, environmental variables may be plotted on the ordination axes, but they are not used to constrain the analysis as they are in Canonical Correspondence Analysis (CCA). This method differs from PCA essentially because it assumes a unimodal relationship between taxa and underlying gradients. CA was run on the data in Canoco, but the results did not reveal any patterns that weren't observed with PCA.

Canonical correspondence analysis (CCA) is a direct gradient analysis method. As with RDA, Canoco allows evaluation of the importance of environmental variables by forward selection when performing CCA. RDA assumes a linear relationship between taxa data and underlying gradients, whereas CCA assumes a unimodal relationship. CCA was run on Canoco with biplot scaling, focussed on inter-sample distances, with no transformation of data, deletion of the same two taxa as in the RDA run above, and manual forward selection of environmental variables using Monte Carlo permutation tests to assess significance. Substrate was almost significant (P=0.055) and explained 0.166 of the variance in the taxa data. 00005 Impact score explained 0.138 of the variance, which was not significant (P=0.08). Running the CCA with only the forward selected substrate variable produced an ordination that clearly separated LBU sites from WCTU sites (Fig. 7).

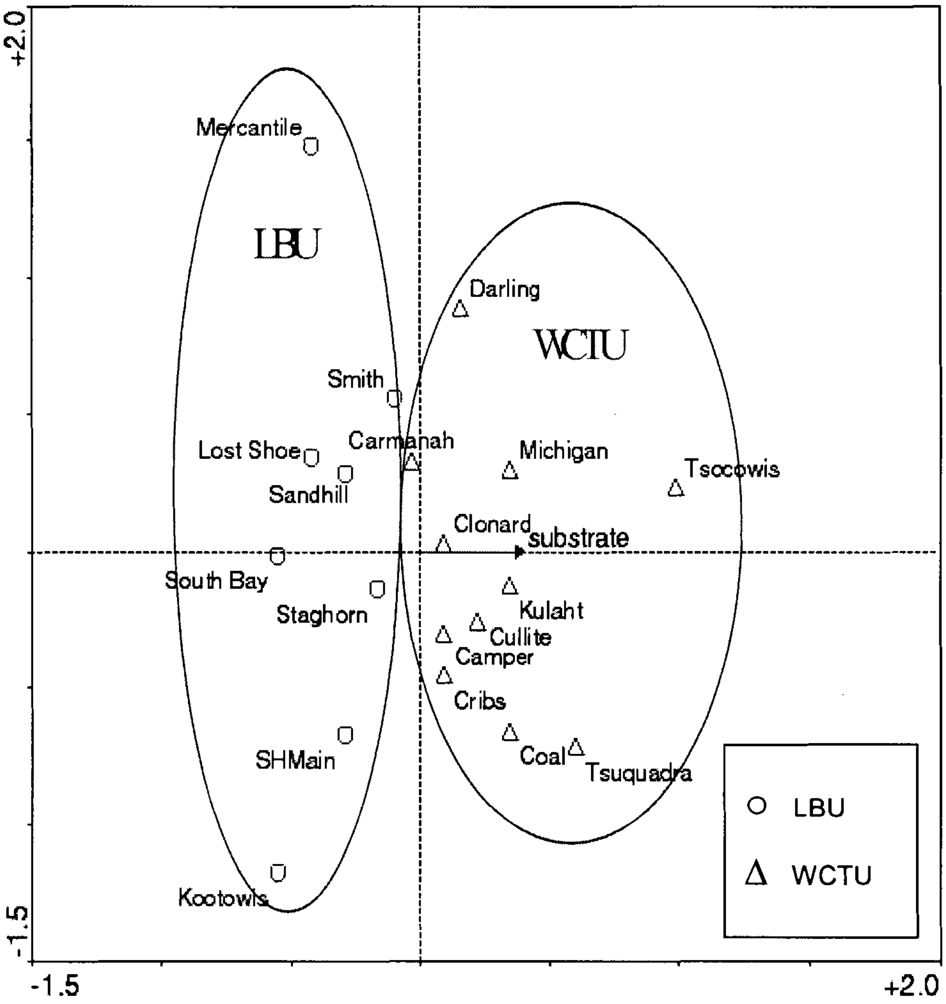

Figure 8. CCA plot of sites in Pacific Rim NPR. Substrate environmental variable was forward selected for inclusion, as the only variable with a significant explanation of variance in the macroinvertebrate taxa (P=0.055). This plot shows the separation between WCTU sites (triangle markers) and LBU sites (circle markers). Ordination produced with Canoco software.

Forward selection of the 00005 impact score variable, despite its lack of significant explanatory power, was attempted in order to explore the potential for ordination axes based on similar underlying gradients (the theoretical "real" impact gradient underlying the sites, for example). The significance of the canonical axes was evaluated with a Monte Carlo permutation test and found to be insignificant (P=0.145). Separation of sites classified as low, medium or high impact, according to their 00005 impact scores (low<5, med 5-20, high>20) by the statistically significant CCA plot of sites with the substrate variable was explored (Fig. 8).

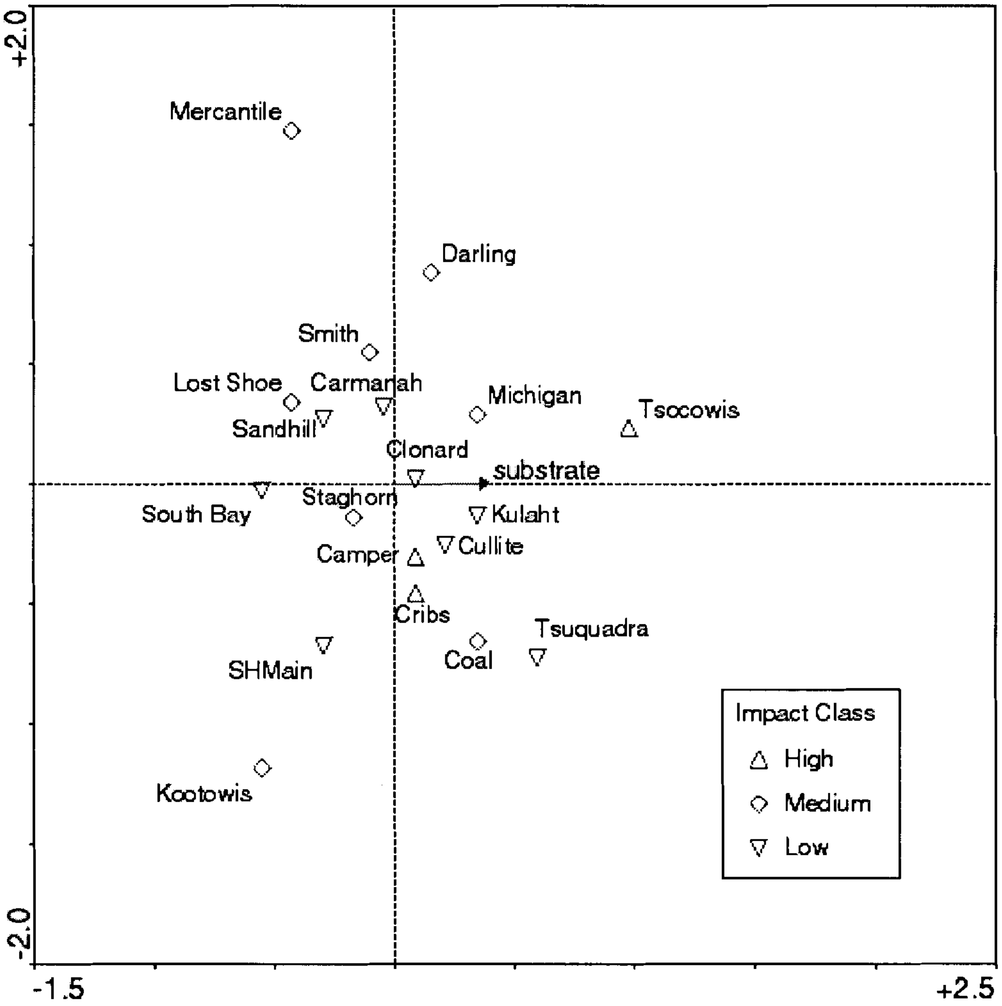

Figure 9. CCA plot of sites in Pacific Rim NPR. Substrate variable was selected for inclusion, and all other environmental variables excluded. The ordination axes were found to explain marginally significant portions of variance in the taxa data (P=0.055), however they did not separate sites well with regard to impact scores. Ordination produced with Canoco software.

Cluster analysis of the study watersheds based on macroinvertebrate assemblages presented patterns similar to the other multivariate analyses, but in a format that forces sites into clusters (Downes *et al.* 2002). Once again, transforming the data to presence-absence improved the ability of the cluster analysis to separate watersheds by their Park unit, but did not improve separation of study watersheds according to impact class. The same sites that routinely plotted away from the main cluster of sites in ordinations (Camper, Kootowis and Tsuquadra), appeared further distant from main site clusters in cluster diagrams as well (Fig. 11). The cluster process, like NMDS, is based on a similarity table. Bray-Curtis and Euclidean Distance measures of similarity are possible, corresponding with unimodal and linear models for the relationship between taxa data and underlying gradients. As mentioned previously, these data are on the cusp between linear and unimodal models. Differences were not apparent, so the Bray-Curtis derived cluster diagram was chosen for discussion.

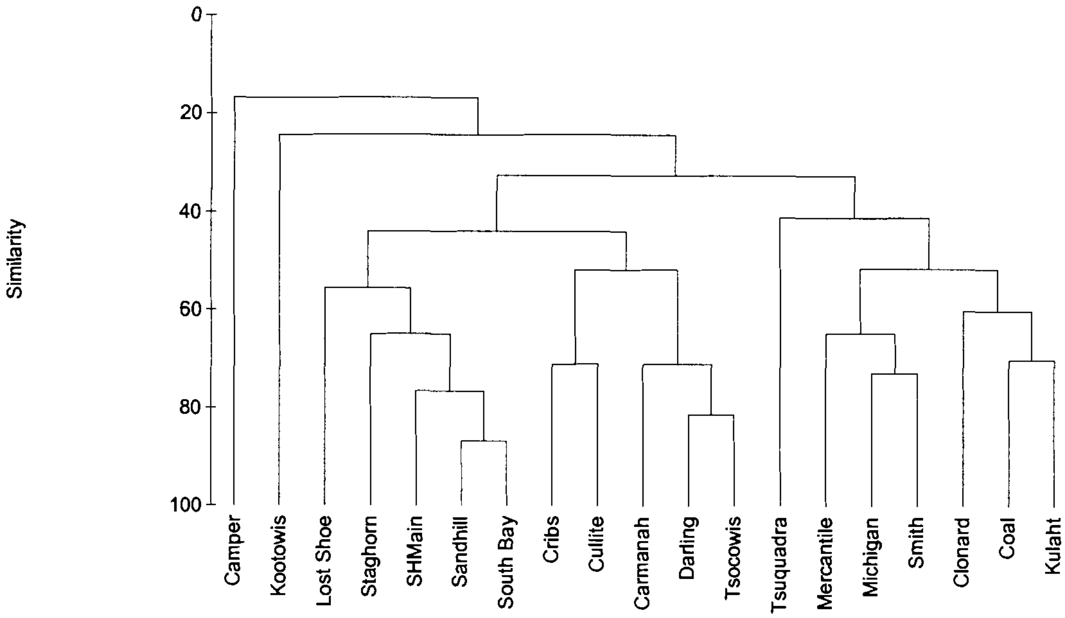

Figure 10. Hierarchical cluster analysis based on Bray-Curtis similarity matrix of presence-absence transformed taxa data, using complete linkage cluster mode. Clustering corresponds well with geographic proximity. Cluster diagram produced with Primer software.

Camper and Kootowis creeks are outliers from the remaining sites. Camper, as discussed above, had very low macroinvertebrate abundance, likely because of the peak flow event during the evening prior to sampling. There are several possible reasons for the separation of Kootowis Creek. Kootowis has several long reaches with little riparian vegetation, including the reach from which samples were collected. Historical logging, right to the banks of Kootowis Creek, resulted in extensive congestion of the creek with woody debris. Since 1994, restoration work has been carried out on most of the Kootowis Creek mainstem and tributaries (Clough 1999). It is possible that the initial degradation, and subsequent intensive restoration, have altered the benthic macroinvertebrate communities now collected from Kootowis Creek. Staghorn and Lost Shoe creeks are similar in many physical and biological respects (Fig. 1), and have undergone restoration work during 2000 and 2001, but to a lesser extent than the work done in Kootowis Creek (Clough 1999).

Other than Camper and Kootowis Creeks, the remaining sites cluster closely with their geographic neighbours in Figure 12, and hence sites from the same Park unit tend to cluster together. Exceptions to this are Mercantile and Smith creeks. Though classified as part of the Long Beach unit because they are located near Ucluelet, northwest of Barkley Sound, they cluster out close to creeks from the northwest end of the West Coast Trail. Mercantile and Smith both have steep headwaters up in the mountains above Ucluelet, likely imposing hydrologic and nutrient regimes similar to the north WCT creeks, and resulting in similar macroinvertebrate assemblages. The remaining LBU creeks are comparatively flat, meandering across Kennedy Flats and Long Beach.

4. Discussion

The variety of analyses carried out on the data reveals several interesting patterns. First, and most importantly, macroinvertebrate assemblages differ sufficiently between the LBU and WCTU of Pacific Rim NPR so that samples from the two units are represented as separate groups in most multivariate analyses, and with many of the tested metrics. The data collected in this study reflected the ecological differences between park units, yet the potential for the same data to discriminate between two or more impact classes is inconsistent, and many patterns observed in the data were not statistically significant.

Successful discrimination between park units, but failure to discriminate between impact classes suggests that the study creeks do not encompass a large enough gradient of impact to assign impact classes with confidence. Spatially, the Long Beach Unit and the West Coast Trail Unit of Pacific Rim NPR are quite close together, separated only by Barkley Sound, approximately 30km across. Their topography, and resultant ecology, is visibly different on satellite imagery (Figs. 2 and 3) and on the ground. Several of the environmental variables measured for the study creeks also demonstrate these differences, as WCTU creeks are typically steeper, with larger substrates than LBU creeks. When canonical correspondence analysis (CCA) was performed, the canonical axes corresponded strongly with substrate and gradient environmental variables. These park unit specific features explained more variation in the macroinvertebrate data than other environmental variables, and more variation than could be attributed to theoretical ordination axes, which may be imagined to include the human impact variable. The multivariate analyses thus support the notion that environmentally dependent ecological variation in macroinvertebrate assemblages of LBU and WCTU present too much noise, relative to the signal of variation resulting from human impacts to ecological integrity. A potential solution to this problem is the separate analysis of creeks in each Park unit, in order to focus more attention on subtle differences among creeks within each unit. The main obstacle to separate analyses is the small number of sample sites, nine and ten sites per Park unit. Running multivariate statistics on a mere nine sites violates most assumptions upon which the statistical methods are based, as discussed above in section 2.5.

Since the multivariate analyses clearly distinguished between creeks from different Park units, based on macroinvertebrate assemblages, the sampling effort and taxonomic resolution must have been adequate. However, finer taxonomic resolution, even just for EPT taxa, may improve the analysis (Hewlett 2000) and is therefore recommended for further biomonitoring work in Pacific Rim NPR. More concise specimen identification would especially benefit metrics based on taxonomic richness, and would also affect relative abundance and other metrics. Improved resolution might not make for major improvement in multivariate analyses, because splitting existing taxa into species would increase the number of rare taxa that do not fit well with multivariate statistical models.

Increasing sampling effort also holds some promise, as better representation of the full macroinvertebrate assemblage would improve ecological and statistical validity of the IBI approach. Research on biological monitoring with benthic macroinvertebrates continues, and some interesting work has been done since this project began. Increasing sampling effort above that recommended by Karr and Chu (1999) is a methodological change that is likely to improve future benthic macroinvertebrate studies in Pacific Rim NPR. Increasing from three to five Surber samples per site would likely have yielded a more complete measure of taxonomic richness (Li *et al.* 2001). Based on the experience of this study, future sampling of macroinvertebrates in Pacific Rim should use five Surber samples per site.

Certain limitations posed by the small area of the park and the relatively unique ecosystems present in the Kennedy Flats area of LBU may be more difficult to overcome, as is the possibility that all creeks flowing through the park are close to the "undisturbed" end of a hypothetical gradient of possible impacts. Inclusion of streams passing through the towns of Hesquiat, Ahousat, Tofino, Ucluelet, Bamfield, and Port Renfrew in future studies could help to define a longer gradient of impacts. Macroinvertebrate collections and analysis for small first and second order streams in the region might provide a sufficient number of undisturbed streams to define reference condition, but such streams are ecologically distinct from continuously flowing streams due to intermittent flows and small size (Suski *et al.* 1998).

The potential range of B-IBI scores was 10 – 50 for each creek. Statistical exploration of the actual scores provided some insight into the limitations of the IBI method, as evident from this project. Final scores were compared with human impact scores determined from satellite analysis of disturbed area in each watershed. Figure 4 shows a poor correlation between B-IBI score and human impact score. This discrepancy suggests that one or both of the indicators failed to measure ecological integrity, as defined in section 1. An alternative explanation is that the landscape disturbances measured by satellite image analysis were not impacting the benthic macroinvertebrate assemblages in the study streams. This seems unlikely, as impacts on benthic macroinvertebrates from logging are well documented (Merritt and Cummins 1996). Considering the gradient of potential impacts – from a pristine creek through increasing levels of landscape disturbance to complete urbanisation and paving of the entire catchment – it is clear that the human impacts to creeks in Pacific Rim NPR occupy only one end of the potential impact gradient. Clearcut logging has impacts on ecological components and processes, but the benthic macroinvertebrate based monitoring methods employed in this study may not have been sensitive enough to detect them. In future, type II error, or "power to detect an effect" should be quantitatively examined, and considered in the design of a biological monitoring protocol for Pacific Rim NPR, in order to reduce this uncertainty about the results.

The poor relationship between B-IBI scores and impact scores suggests that they are not measuring the same thing, or that one or both is not measuring what is intended (the ecological structure and function that has been defined as ecological integrity), or that one or both are failing to measure anything. The impact scoring method may have failed to successfully measure ecological disturbance in the study watersheds –ecological impacts other than recently logged areas may be affecting ecological integrity in the systems. Forest management in catchments may only strongly disturb the ecology of benthic macroinvertebrates for a short period of time, with more subtle effects persisting for decades following harvest. Peak flow increases have been shown to occur, but only smaller one and two year interval flow events appear to increase, with no change detected for larger flows occurring at intervals of five years or greater (Beschta *et al.* 2000). Sedimentation in streams may be the most ecologically disruptive stressor caused by forestry, but sedimentation increases typically return to baseline levels within 3-5 years after logging (Harden and Matthews 2000; Canadian Council of Forest Ministers 1997). However, the 00005 impact score should have represented recent logging well enough to detect 3-5 year post logging sediment impacts. The B-IBI may have failed to measure ecological integrity, because of insufficient replication in data collection or a failure to effectively calibrate the B-IBI. The B-IBI may have failed to detect a significant difference in ecological integrity among study watersheds because the difference between watersheds is too subtle – the gradient of impacts is not large enough for B-IBI to distinguish more than one integrity class.

5. Research and Management Implications

Despite the difficulty in accurately attributing differences in benthic macroinvertebrate assemblages to human impacts within watersheds in and near Pacific Rim NPR, the macroinvertebrate inventory provides benchmark ecological data, which is an important part of the ongoing EI monitoring strategy for Parks Canada (Parks Canada 2000b). Lessons learned from this biological monitoring project may be applied to future monitoring efforts in Pacific Rim NPR, and elsewhere in the National Parks system.

The ramifications of failing to conduct *a priori* power analysis and adaptive experimental design to test assumptions is well demonstrated by this study. The reviewed literature provided a reasonable experimental design, but methods clearly need to be fine tuned for application to a new study region and tailored to the analyses that will eventually be performed. Data collection was designed to meet the requirements of the B-IBI method as stated in Karr and Chu (1999). Results suggest that greater sampling effort, over a larger regional area, may have given more discriminatory power to the B-IBI. However, the potential of the B-IBI to provide definitive biological monitoring results with minimal resource requirements has proven not to be the case.

If sufficient resources can be allocated to benthic biomonitoring in the future, data collection should be undertaken with the goal of defining reference conditions in Pacific Rim NPR, in order to develop a predictive biomonitoring system supported by rigorous multivariate analysis and demonstrated effective metrics. Effective application of the reference condition approach to benthic macroinvertebrate monitoring also requires more rigorous measurement of environmental variables for each study creek. Combining biological monitoring with planned and existing physico-chemical, water quality, and landscape change monitoring programs will provide a diverse multivariate dataset from which to build a more sensitive overall monitoring program. Continuation of macroinvertebrate monitoring in Pacific Rim NPR will permit resolution of many problems encountered in this initial study. Site specific lessons learned from analysis of the first set of samples, and described in this document, should be applied to the second (and subsequent) field seasons, resulting in a much stronger biological monitoring program.

A noteworthy implication of this study for management is the simple possibility that methods may work well in several places, but fail to produce expected results in a novel application, such as a different scale, type of ecosystem, etc. The importance of an overall monitoring and assessment framework is clear; however there must be an acknowledgement of the need for development or adaptation of locally appropriate methods.

Biological monitoring has been established as an acceptable approach for assessing ecological integrity around the world, though all methods have strengths and weaknesses, and all have uncertainty in their results. Methods continue to be developed and refined by researchers and managers in British Columbia and throughout the Pacific Northwest region of North America. Protected areas, ecologically stressed though many may be, provide some relatively undisturbed ecosystems that are crucial for the collection of baseline data and description of reference conditions, upon which good biomonitoring programs are based. Benthic macroinvertebrates possess all the criteria of the "chosen indicator set" endorsed by Parks Canada, including cost effectiveness in collection, analysis and interpretation. Volunteers can effectively collect them (Fore *et al.* 2001), biologists at the field unit level can become proficient at identification of assemblages for their respective park or region (Carter and Resh 2001), and a large and growing body of professional services, academic literature, and management resources exists today.

6. Literature Cited

Angermeier,P.L. and Karr,J.R. 1986. Applying an index of biotic integrity based on stream-fish communities: Considerations in sampling and interpretation. North American Journal of Fisheries Management **6**: 418-429.

Angermeier,P.L. and Karr,J.R. 1994. Biological integrity versus biological diversity as policy directives: Protecting biotic resources. Bioscience **44**: 690-697.

Baker,S.C. and Sharp,H.F.J. 1998. Evaluation of the recovery of a polluted urban stream using the Ephemeroptera-Plecoptera-Trichoptera index. Journal of Freshwater Ecology **13**: 229-234.

Barbour,M.T., Gerritsen,J., Griffith,G.E., Frydenborg,R., McCarron,E., White,J.S., and Bastian,M.L. 1996. A framework for biological criteria for Florida streams using benthic macroinvertebrates. Journal of the North American Benthological Society **15**: 185-211.

Barbour,M.T., Stribling,J.B., and Karr,J.R. 1995. Multimetric approach for establishing biocriteria and measuring biological condition. *In* Biological assessment and criteria: Tools for water resource planning and decision making. *Edited by* W.S.Davis and T.P.Simon. CRC Press, Inc., Boca Raton, Florida pp. 63-77.

Bartlein,P.J., Whitlock,C., and Shafer,S.L. 1997. Future climate in the Yellowstone National Park region and its potential impact on vegetation. Conservation Biology **11**: 782-792.

Bell,S. and Morse,S. 1999. Sustainability Indicators: Measuring the immeasurable. Earthscan, UK.

Beschta,R.L., Pyles,M.R., Skaugset,A.E., Surfleet,C.G. 2000. Peak flow responses to forest practices in the western cascades of Oregon, USA. Journal of Hydrology **233**: 102-120.

Bolt,G. Scientists see the future of global warming here. The Register-Guard. 10-8-2000. Eugene, Oregon, USA.

Brooks,K.N., Ffolliott,P.F., Gregersen,H.M., and Debano,L.F. 1997. Infiltration, runoff, and streamflow. *In* Hydrology and the management of watersheds. Iowa State University Press, Ames, Iowa pp. 69-92.

Brooks,R.P., O'Connel,T.J., Wardrop,D.H., and Jackson,L.E. 1998. Towards a regional index of biological integrity: The example of forested riparian ecosystems. Environmental Monitoring and Assessment **51**: 131-143.

Canada 2000. Canada National Parks Act. SC 2000, c. 32. 10-20-2000.

Canadian Council of Forest Ministers 1997. Criteria and indicators of sustainable forest management in Canada: Technical Report. Natural Resources Canada – Canadian Forest Service.

Carter,J.L. and Resh,V.H. 2001. After site selection and before data analysis: sampling, sorting, and laboratory procedures used in stream benthic macroinvertebrate monitoring programs by USA state agencies. Journal of the North American Benthological Society **20**: 658-682.

Clough,D.R. 1999. Kootowis, Staghorn, Lost Shoe Watershed restoration project, KWRP: Summer completion report: Instream Work (Aug. 3rd-27th, 1999). D.R. Clough Consulting.

Cuffney,T.F., Gurtz,M.E., and Meador,M.R. 1993. Methods for collecting benthic invertebrate samples as part of the National Water-Quality Assessment Program. US Geological Survey No. 93-406.

Doberstein,C.P., Karr,J.R., and Conquest,L.L. 2000. The effect of fixed count subsampling on macroinvertebrate biomonitoring in small streams. Freshwater Biology **44**: 355-371.

Dolan,B., Lieff,B., and MacDonald,R. 1992. "Toward sustainable ecosystems": A Canadian Parks Service strategy to enhance ecological integrity. Canadian Parks Service, Environment Canada.

Dorner,B. 2002. A comparative analysis of landscape structure in managed and unmanaged watersheds. PhD dissertation. Simon Fraser University, Burnaby, B.C.

Downes,B.J., Barmuta,L.A., Fairweather,P.G., Faith,D.P., Keough,M.J., Lake,P.S., Mapstone,B.D., and Quinn,G.P. 2002. Monitoring ecological impacts: Concepts and practice in flowing waters. Cambridge University Press, UK.

Dudley,N. and Stolton,S. 1999. Partnerships for protection: new strategies for planning and management for protected areas. Earthscan, London.

Ecosystem Management Task Force 1992. "Toward Sustainable Ecosystems": A Canadian Parks Service strategy to enhance ecological integrity. Canadian Parks Service, Environment Canada.

Fairweather,P.G. 1999. Determining the 'health' of estuaries: Priorities for ecological research. Australian Journal of Ecology **24**: 441-451.

Fausch,K.D., Karr,J.R., and Yant,P.R. 1984. Regional application of an index of biotic integrity based on stream fish communities. Transactions - American Fisheries Society **113**: 39-55.

Fore,L.S., Karr,J.R., and Conquest,L.L. 1994. Statistical properties of an index of biological integrity used to evaluate water-resources. Canadian Journal of Fisheries and Aquatic Sciences **51**: 1077-1087.

Fore,L.S., Paulsen,K., and O'Laughlin,K. 2001. Assessing the performance of volunteers in monitoring streams. Freshwater Biology **46**: 99-108.

Fore,L.S., Karr,J.R., and Wisseman,R.W. 1996. Assessing invertebrate responses to human activities: evaluating alternative approaches. Journal of the North American Benthological Society **15**: 212-231.

Forward, C.N. 1979. Vancouver Island: Land of contrasts. Western Geographic Series, Vol. 17. Department of Geography, University of Victoria. 350pp.

Gerritsen,J., Barbour,M.T., and King,K. 2000. Apples, oranges, and ecoregions: on determining pattern in aquatic assemblages. Journal of the North American Benthological Society **19**: 487-496.

Goldstein,B.D. 1999. The precautionary principle and scientific research are not antithetical. Environmental Health Perspectives **107**: A594-A595.

Green,R.N. and Klinka,K. 1994. A field guide to site identification and interpretation for the Vancouver Forest Region. BC Ministry of Forests.

Grumbine,R.E. 1994. What is ecosystem management? Conservation Biology **8**: 27-38.

Harden,C.P. and Mathews,L. 2000. Rainfall response of degraded soil following reforestation in the Copper Basin, Tennessee, USA. Environmental Management **26**: 163-174.

Hawkins,C.P. and Vinson,M.A. 2000. Weak correspondence between landscape classifications and stream invertebrate assemblages: implications for bioassessment. Journal of the North American Benthological Society **19**: 501-517.

Hewlett,R. 2000. Implications of taxonomic resolution and sample habitat for stream classification at a broad geographic scale. Journal of the North American Benthological Society **19**: 352-361.

Jager,J.C. and Looman,C.W.N. 1995. Data Collection. *In* Data analysis in community and landscape ecology. *Edited by* R.H.G.Jongman, C.J.F.ter Braak, and O.F.R.van Tongeren. Cambridge University Press, Cambridge, UK pp. 10-28.

Jones,J.A. and Grant,G.E. 1996. Peak flow responses to clear-cutting and roads in small and large basins, western cascades, Oregon. Water Resources Research **32**(4): 959-974.

Kalff,S.A. 1995. A proposed framework to assess cumulative environmental effects in Canadian National Parks. Minister of Canadian Heritage No. #1.

Karr,J.R. 1981. Assessment of biotic integrity using fish communities. Fisheries **6**: 21-27.

Karr,J.R. and Chu,E.W. 1999. Restoring life in running waters: Better biological monitoring. Island Press, Washington, D.C.

Karr,J.R. and Dudley,D.R. 1981. Ecological perspective on water quality goals. Environmental Management **5**: 55-68.

Li,J., Herlihy,A., Gerth,W., Kaufman,P., Gregory,S., Urquhart,S., and Larsen,D.P. 2001. Variability in stream macroinvertebrates at multiple spatial scales. Freshwater Biology **46**: 87-97.

Liang,S.H. and Menzel,B.W. 1997. A new method to establish scoring criteria of the index of biotic integrity. Zoological Studies **36**: 240-250.

Mermillod-Blondin,F., Creuze Des Chatelliers,M., Marmonier,P., and Dole-Olivier,M.J. 2000. Distribution of solutes, microbes and invertebrates in river sediments along a riffle-pool-riffle sequence. Freshwater Biology **44**: 255-269.

Merritt,R.W. and Cummins,K.W. 1996. An introduction to the aquatic insects of North America. Kendall/Hunt Publishing Company, Dubuque, Iowa.

Morley,S.A. and Karr,J.R. 2002. Assessing and restoring the health of urban streams in the Puget Sound Basin. Conservation Biology **16**: 1498-1509.

MSRM and MWLAP 2002. BC Watershed Atlas. BC Ministries of Sustainable Resource Management and Water,Land and Air Protection.

Munn,R.E. 1999. Keeping Ahead: The Inclusion of Long-Term "Global" Futures in Cumulative Environmental Assessments. Munn, R. E. 10-27-1993.

Muller,J.E. 1974. Geology of Pacific Rim National Park. Report for Indian and Northern Affairs, Parks Canada. Geological Survey of Canada.

Page,R., Bayley,S., Cook,J.D., Green,J.E., and Ritchie,J.R.B. 1996. Banff-Bow Valley: At the crossroads. Summary report of the Banff-Bow Valley Task Force. Prepared for the Honourable Sheila Copps, Minister of Canadian Heritage, Ottawa, ON. Summary Report.

Parks Canada 1994a. Guiding principles and operational policies. No. Cat No R62-275/1994E.

Parks Canada 1994b. State of the Parks 1994 Report. Canadian Heritage and Parks Canada.

Parks Canada 1997. State of the Parks 1997 Report. Minister of Public Works and Government Services Canada.

Parks Canada 2000a. "Unimpaired for future generations"? Conserving ecological integrity with Canada's National Parks. Volume I: A call to action. Blackbird Design.

Parks Canada 2000b. "Unimpaired for future generations"? Conserving ecological integrity with Canada's National Parks. Vol. II: Setting a new direction for Canada's National Parks. Minister of public works and government services.

Pellerin,S.M. 1995. Tofino Airport Environmental Audit. Report No. 95-2605-04. M.M. Dillon Limited Consulting Engineers, Planners and Environmental Scientists.

Rabeni,C.F. and Doisy,K.E. 2000. Correspondence of stream benthic invertebrate assemblages to regional classification schemes in Missouri. Journal of the North American Benthological Society **19**: 419-428.

Rapport,D.J., Gaudet,C., Karr,J.R., Baron,J.S., Bohlen,C., Jackson,W., Jones,B., Naiman,R.J., Norton,B., and Pollock,M.M. 1998. Evaluating landscape health: integrating societal goals and biophysical process. Journal of Environmental Management **53**: 1-15.

Reece,P.F. and Richardson,J.S. 2000. Biomonitoring with the reference condition approach for the detection of aquatic ecosystems at risk. *In* Proceedings of a conference on the biology and management of species and habitats at risk. *Edited by* L.M Darling. Kamloops, BC. BC Ministry of Environment, Lands and Parks and University College of the Cariboo.

Relyea,C.D., Minshall,G.W., and Danehy,R.J. 2000 Stream insects as bio-indicators of fine sediment. *In* Proceedings of Watershed Management 2000 Conference. 1-23-2000. Alexandria, Virginia, Water Environment Federation.

Rempel,L.L., Richardson,J.S., and Healey,M.C. 1999. Flow refugia for benthic macroinvertebrates during flooding of a large river. Journal of the North American Benthological Society **18**: 34-48.

Resh,V.H., Rosenberg,D.M., and Reynoldson,T.B. 2000. Selection of benthic macroinvertebrate metrics for monitoring water quality of the Fraser River, British Columbia: implications for both multimetric approaches and multivariate models. *In* Assessing the biological quality of fresh waters: RIVPACS and other techniques. *Edited by* J.F.Wright, D.W.Sutcliffe, and M.T.Furse. Freshwater Biological Association, Ambleside, Cumbria pp. 195-206.

Reynoldson,T.B. and Rosenberg,D.M. 1998. Benthic invertebrate community structure.

Reynoldson,T.B., Rosenberg,D.M., and Resh,V.H. 2001. Comparison of models predicting invertebrate assemblages for biomonitoring in the Fraser River catchment, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences **58**: 1395-1410.

Richardson,J.S. and Kiffney,P.M. 2000. Responses of a macroinvertebrate community from a pristine, southern British Columbia, Canada, stream to metals in experimental mesocosms. Environmental Toxicology and Chemistry **19**: 736-743.

Rosenfeld,J. 1998. Sensitivity of anadromous cutthroat trout to forest harvest. BC Ministry of Fisheries No. Annual Progress Report: HQ96293-RE.

Rosenfeld,J., Macdonald,S., Foster,D., Amrhein,S., Bales,B., Williams,T., Race,F., and Livingstone,T. 2000. Unpublished Work. Importance of small streams as rearing habitat for sea-run cutthroat trout and coho salmon.

Roth,N.E., Allan,J.D., and Erickson,D.L. 1996. Landscape influences on stream biotic integrity assessed at multiple spatial scales. Landscape Ecology **11**: 141-156.

Rowe,A., Redhead,B., and Dobell,D. 1998. Workshop on Assessing Ecological Status: Proceedings. 67 pp. 10-5-1998.

Sandin,L. and Johnson,R.K. 2000. Ecoregions and benthic macroinvertebrate assemblages of Swedish streams. Journal of the North American Benthological Society **19**: 462-474.

Searle,R. 2000. Death by a thousand cuts. *In* Phantom Parks: The struggle to save Canada's National Parks. Key Porter Books Limited, Toronto, Canada pp. 27-44.

Slocombe,D.S. 1998a. Lessons from experience with ecosystem-based management. Landscape and Urban Planning **40**: 31-39.

Slocombe,D.S. 1998b. Defining goals and criteria for ecosystem-based management. Environmental Management **22**: 483-493.

Smith,R., Eckenrode,J., Gaul,A., Masemer,D., Poerstel,S., Rodriguez,H., Stough,M., and Ambler,J. 2000. Stream macroinvertebrates, the riparian forest, and stream habitat as indicators of human disturbance. Journal of the Pennsylvania Academy of Science **73**: 178-179.

SPSS 1999. SPSS for Windows. Release 10.0.5. Standard version.

Storck,P., Bowling,L., Wetherbee,P., and Lettenmaier,D. 1998. Application of a GIS-based distributed hydrology model for prediction of forest harvest effects on peak stream flow in the Pacific Northwest. Hydrological Processes **12**: 889-904.

Strahler,A.N. 1957. Quantitative analysis of watershed geomorphology. Transactions - American Geophysical Union **38**: 913-920.

Suski,A., Beasley,B., Price,K., and Richardson,J.S. 1998. The ecological requirements for riparian buffers around continuously-flowing, seasonal and ephemeral headwater streams in Clayoquot and Barkley Sounds. The Science Council of

British Columbia, Forest Renewal BC Research Program, Long Beach Model Forest Society No. PA97308-7RE.

ter Braak,C.J.F. 1995. Ordination. *In* Data analysis in community and landscape ecology. *Edited by* R.H.G.Jongman, C.J.F.ter Braak, and O.F.R.van Tongeren. Cambridge University Press, Cambridge, UK pp. 78-90.

ter Braak,C.J.F. and Smilauer,P. 1998. CANOCO reference manual and user's guide to Canoco for Windows: Software for canonical community ordination (version 4). Microcomputer Power, Ithaca, NY.

Thomas,R.B. and Megahan,W.F. 1998. Peak flow responses to clear cutting and roads in small and large basins, western cascades, Oregon: A second opinion. Water Resources Research **34**(12):3393-3403.

Thorp,J.H. and Covich,A.P.(*eds.*). 2001. Ecology and classification of North American freshwater invertebrates. Second Edition. Academic Press, San Diego.

Toews, D.A.A. and Moore,M.K. 1982. The effects of streamside logging on large organic debris in Carnation Creek. Land Use Unit, Habitat Protection Division, Field Services Branch, Pacific Region, Department of Fisheries and Oceans.

Turner,N.J. 1999. "Time to Burn" Traditional Use of Fire to Enhance Resource Production by Aboriginal Peoples in British Columbia. *In* Indians, Fire and the Land in the Pacific Northwest. *Edited by* R.Boyd. Oregon State University Press, Corvalis pp. 185-218.

Waite,I.R., Herlihy,A., Larsen,D.P., and Klemm,D.J. 2000. Comparing strengths of geographic and nongeographic classifications of stream bethic macroinvertebrates in the Mid-Atlantic Highlands, USA. Journal of the North American Benthological Society **19**: 429-441.

Watson,A.J., Bakker,D.C.E., Ridgwell,A.J., Boyd,P.W., and Law,C.S. 2000. Effect of iron suply on Southern Ocean CO_2 uptake and implications for glacial atmospheric CO_2. Nature **407**: 730-733.

Wente,S.P. 2000. Proximity-based measure of land use impacts to aquatic ecosystem integrity. Environmental Toxicology and Chemistry **19**: 1148-1152.

Woodley,S. 1997. Science and protected area management: an ecosystem based perspective. *In* National Parks and Protected Areas. *Edited by* J.G.Nelson and R.Serafin. Springer-Verlag, Berlin/Heidelberg pp. 11-21.

Woodley,S. 1998. *In* Workshop on Assessing Ecological Status: Proceedings. *Edited by* Rowe, A., Redhead, B., and Dobell, D. 1998. 67 pp. 10-5-1998.

Zinkan,C., Harrison,G., Westhaver,A., Stinson,D., and Webber,G. 1990. Report of the Science and Protection Task Force: A report to the Canadian Parks Service

Western Region Management Committee. Canadian Parks Service Western Region.