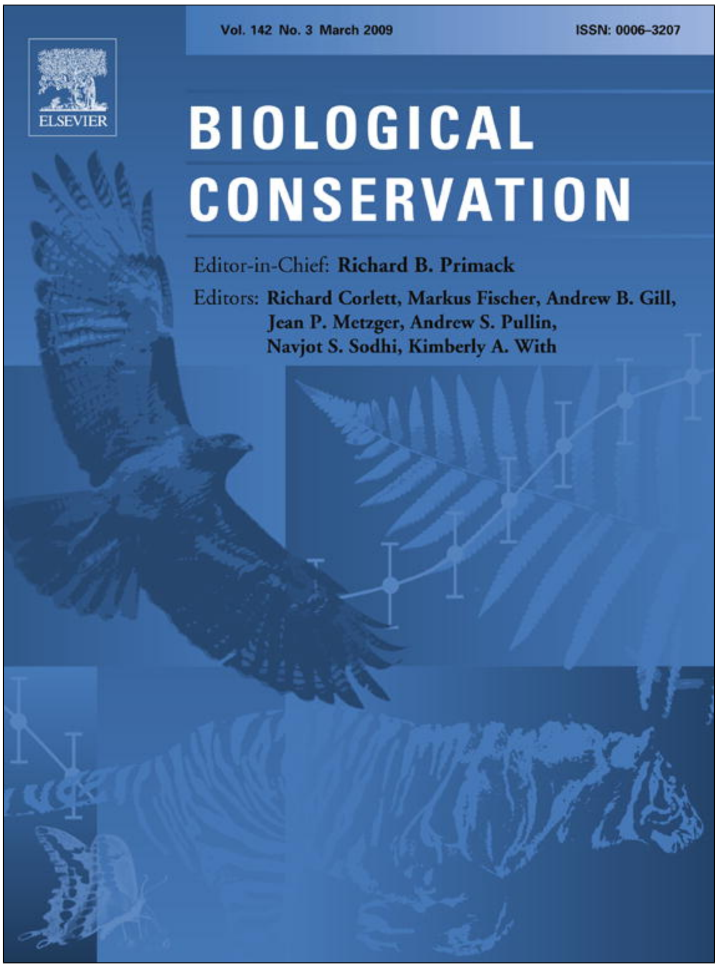
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Evaluating ecological integrity in national parks: Case studies from Canada and South Africa

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A B S T R A C T

Many existing parks are currently experiencing difficulties in achieving their conservation aims, yet they remain an important option for maintaining and enhancing the conservation of biological diversity and ecosystem processes. Critics have claimed that many national parks cannot continue to protect the biological resources within their borders, and the sustainability of these areas over the long-term is in question. Ways need to be found to strengthen those that are failing, and to understand and replicate those that are succeeding. This paper presents the empirical results from a systematic evaluation of how effectively six case study national parks and national park reserves in Canada and South Africa have been protecting ecological integrity. Several parks were effective at addressing the priorities for which they had monitoring data, however the effectiveness rating of each park decreased when all indicators, including those identified as priorities but lacking monitoring data, were analysed. This indicates that the parks had generally identified more priority indicators than they were actually able to address (for many reasons, including lack of budget or trained staff, managerial challenges). Overall, a systematic approach to evaluating ecological integrity in national parks is recommended as the managers of protected areas cannot be expected to conserve the biological diversity and ecosystem processes within their borders if they are unaware of the ecological status of the park's biodiversity. The paper concludes with several practical recommendations for monitoring ecological integrity in national parks.

1. Introduction

National parks are considered fundamental to efforts to protect biodiversity around the world (Gaston et al., 2006). Yet, many existing parks are currently experiencing difficulties in achieving their conservation aims, and their long-term sustainability has been questioned (Bruner et al., 2001). Critics have claimed that national parks cannot be expected to carry the burden of maintaining biodiversity (Eagles, 1993), that they do not necessarily protect biotic integrity within their borders (Terborgh, 2004; Bruner et al., 2001; Salafsky et al., 2002), or that they have been poorly located from the standpoint of biodiversity conservation (Scott et al., 2001; Rodrigues et al., 2004). The global network of parks currently is nonetheless a key option for maintaining and enhancing biodiversity conservation; ways need to be found to strengthen those that are failing (Terborgh and van Schaik, 2002), and to understand and replicate those that are succeeding.

Efforts have been made to improve the sustainability of national parks by evaluating the effectiveness of management actions, and incorporating the findings back into management strategies (Dudley et al., 1999; Parrish et al., 2003;

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Hockings et al., 2004, 2006). Effectiveness evaluations focus on outcomes, provide a more direct measure of the impact of management than those that only target inputs or processes, and assess if management actions resulted in the intended outcomes (Salafsky et al., 2002; Salzer and Salafsky, 2006). If undertaken in a systematic manner, such evaluations can encourage adaptive management by reviewing actions taken and assessing whether they produced the desired results (Hawthorn et al., 2002; Hockings et al., 2006; Pullin et al., 2004). However, many evaluations have been anecdotal rather than empirical (Saterson et al., 2004), a systematic approach has not always been used, and only a limited number of published studies have addressed ecological effectiveness in protected areas (Gaston et al., 2006). And although effectiveness evaluations lend themselves quite easily to empirical investigation (Bingham and Felbinger, 2002), the availability of data is a major constraint (Hawthorn et al., 2002). For many reasons, including lack of budget or trained staff and managerial challenges, many national parks do not yet possess adequate monitoring and evaluation programs. In lieu of sufficient monitoring data, status and trend assessments can be used to evaluate the status of ecological integrity. Status assessments focus on the question "how is the biodiversity we care about doing?" (Salzer and Salafsky, 2006, p. 311), and are an ideal way to prime a national park for a full effectiveness evaluation at a later date.

This paper presents the results from a systematic evaluation of how effectively six national parks and national park reserves in Canada and South Africa have been protecting ecological integrity. An ecosystem has integrity when its dominant ecological characteristics (composition, structure, function) and processes occur within their natural ranges of variation, and can withstand and recover from perturbations caused by natural environmental or human factors (Parrish et al., 2003). Evaluations based on ecological integrity are holistic as they include such concerns as intactness, species viability, ecological processes and functioning, and the threats and stressors facing a protected area (Ervin, 2003). In this study, a national park was considered ecologically effective if it achieved park management objectives in a manner that sustained biodiversity and ecosystem processes while abating threats (*sensu* Ervin, 2003).

2. Methods

The goal of this study was to systematically evaluate how effectively national parks were protecting ecological integrity. To do this, we selected six case study parks in Canada and South Africa and evaluated each case study using various data sources against a set of criteria and indicators and using the analytic procedures described below.

2.1. *Selection of national parks for the study*

The study was restricted to Canada and South Africa because both countries possess functioning predator–prey cycles, maintain extensive and well-established national parks using comparable management styles, and for logistical reasons. Based on expert opinion and knowledge of national parks in these countries, purposive sampling (Babbie and Benaquisto, 2002) was used to select the IUCN Category II (IUCN, 1994) national parks. Because of the broader aims of the project (a study of Indigenous co-management and access to national parks), parks were selected on the basis of the explicit presence or absence of a co-management board involving local Indigenous or tribal groups, as well as to those having a management plan and monitoring data.

Specifically, the national parks and national park reserves included in this study were: Kluane, Gwaii Haanas and Pacific Rim National Park Reserves and Waterton Lakes National Park in Canada, and the Kruger and Kgalagadi National Parks in South Africa. Kluane and Waterton Lakes were selected because they had very explicit management objectives identified in park management plans. Gwaii Haanas and the Kgalagadi were selected as they had less explicit management objectives in their management plans than Kluane and Waterton Lakes, though there was ecological monitoring within the parks. Pacific Rim had the least explicit management statement of all the parks. The Kruger is unique in this study and was selected because it uses the *Thresholds of Potential Concern* (*TPC*) approach. TPCs, essentially the upper and lower limits along a continuum of change in selected environmental indicators, are a set of operational goals that together define the spatiotemporal heterogeneity conditions for which the Kruger ecosystem is managed (Biggs and Rogers, 2003). The case studies varied in size, regional ecosystem type, co-management strategy, and their main management and conservation issues (Table 1).

2.2. *Selection of criteria and indicators of ecological integrity*

Woodley (1993) has proposed a framework for monitoring ecological integrity in national parks that includes three general components – biodiversity, ecosystem processes, and stressors. Parks Canada uses this framework as a set of criteria for evaluating the ecological integrity of national parks: conservation of biological diversity (in order to account for species viability); conservation of ecosystem processes (in order to assess the functionality of an ecosystem); and adaptation to and mitigation of stressors and threats (in order to monitor and reduce negative impacts) (Canadian Heritage, 1998; Parks Canada Agency, 2005). Using these as the criteria in our evaluation, we outlined a preliminary list of indicators through an analysis of management plans and management direction statements from a purposive sample of 14 national and provincial parks in Canada, Australia and South Africa (see Timko and Satterfield, 2008). Investigation of six of these national parks allowed the list of indicators generated inductively from case examination to complement those generated deductively from the assessment of management plans (Boyatzis, 1998). While it is always possible to utilize a very long list of indicators, we consider that the indicators evaluated in this study are specifically relevant to the concept of ecological integrity. In particular, the indicators in three of the Parks Canada case studies were drawn directly from each park's *State of the Park Report* (SoPR). SOPRs are focused on assessing ecological integrity (the list of indicators evaluated for Pacific Rim will be included in that park's first SoPR, which is due to

Table 1 – Distinguishing characteristics of six case study national parks in Canada and South Africa involved in the evaluation of ecological effectiveness.

National Park	Country and location	Latitude, longitude (decimal degrees)	Year established	Size (sq km)	Regional description	Main management/ conservation issues
Waterton Lakes National Park	Canada, SW corner of Alberta, northern part of the Waterton-Glacier international peace park with Glacier national park, Montana, USA	49 01 24 N, 113 55 42 W	1895	525	Crown of the continent ecosystem, rocky mountains	Small size of park relative to large migratory wildlife using the park; external influences from increasing human populations; climate change
Kluane National Park and Reserve	Canada, SW corner of Yukon territory	61 00 49 N, 138 31 31 W	1976	21,980	Northern coast mountains natural region	Climate change, predator/prey interactions; forest pests
Gwaii Haanas National Park Reserve and Haida Heritage Site	Canada, 130 km off northwest coast of British Columbia	52 18 20 N, 131 24 18 W	1993	1470	Pacific coast mountains natural region	Spread of invasive and alien biota; seabird conservation
Pacific Rim National Park Reserve	Canada, west side of Vancouver Island	49 03 05 N, 125 42 46 W	1970	499	Pacific coast mountains natural region	Narrowness of the Long beach unit, anthropogenic impacts on water quality, shoreline protection, large numbers of tourists
Kruger National Park	South Africa, eastern Mpumulanga and Limpopo provinces	24 06 13 S, 31 20 41 E	1898	19,485	South African Lowveld ecoregion	Alien biota; water quantity; fire management; ungulates; carnivores; heterogeneity; large population density on border of park
Kgalagadi National Park	Northern tip of Northern Cape province bordering Namibia and Botswana	26 25 48 S, 20 37 39 E	1931	9591	Southern Kalahari ecoregion	Native vegetation, ungulate migration, predator/prey interactions

be completed in fall 2008). Kruger's TPC program provided the list of indicators being monitored as priorities in the park. The indicators selected for the Kgalagadi have not been associated previously with any formal assessment by the park, but are considered key indicators of ecological integrity in the park.

2.3. Data collection

The monitoring data and information used to evaluate the ecological integrity of each park were collected during site visits between October 2005 and February 2007, and through subsequent correspondence as necessary. All data used in the evaluations were obtained directly from the park staff or private researchers working in the parks. If a SoPR was available for a park, its list of identified indicators and status and trend results were used as that park's evaluation. For all other parks, a staff biologist from the relevant park was asked to review and comment on the list of indicators to ensure their relevance to park management actions. This was important as the park management plans from Pacific Rim and Kgalagadi were older (1994 and 2003, respectively), and monitoring data were used for several indicators that had not been identified as priorities in these plans. For the Kgalagadi, this was also necessary because monitoring data were limited and the park's management plan only broadly identified species of concern rather than explicit management goals for target species. (Most indicators for the Kgalagadi were evaluated for the national park; however several indicators were also evaluated for the much larger Kgalagadi Transfrontier Park, depending on the availability of monitoring data).

As an essential component of this study was to evaluate the management targets important to each park, our evaluation for some parks included data previously obtained from population surveys for specific species, water quality, and plant distribution. Concurrently, SoPRs were used if available, and included broader indicators such as songbirds or seabirds. Unstructured interviews were conducted with park ecologists to complement the monitoring data, and to provide expert opinion on status and trend of indicators where monitoring data were not available. The number of indicators evaluated for each park varied from 17 for Waterton Lakes to 40 for Kruger, so the individual context and the differences among parks in terms of the focal species, specific threats, etc. could be accurately reflected (Tables 2 and 3).

2.4. Data analysis

The following four main components were involved in calculating the effectiveness with which the parks protected ecological integrity: indicator assessment and rating; conversion of indicator ratings into numerical values; calculation of the effectiveness with which ecological integrity was protected; and completion of a sensitivity analysis.

2.4.1. Indicator assessment and rating

2.4.1.1. Determining indicator status. Each indicator was assessed according to the following hierarchy:

- SoPR ratings for each indicator, if available,
- monitoring data evaluated according to Parks Canada's Ecological Integrity monitoring program (Parks Canada Agency, 2007a),
- other monitoring data,
- expert opinion, and
- data from published or unpublished reports.

Parks Canada's ecological integrity monitoring program (Parks Canada Agency, 2007a) was selected for three reasons: the majority of the parks involved in this study were Canadian parks falling under Parks Canada's jurisdiction, managers from several of these parks had just completed an SoPR and those results could be directly used in this study and, provided monitoring data was available, the methodology for determining status and trend was simple, straight forward to use, and easily replicable.

SoPRs were used for three parks (Waterton Lakes, Kluane, Gwaii Haanas), and evaluations using a combination of status and trend assessments, effectiveness evaluations, and expert opinion were completed for the remaining three parks (Pacific Rim, Kluane, Kgalagadi). SoPR results for Gwaii Haanas were also complemented by an evaluation of monitoring data from introduced rats (*Rattus rattus* and *Rattus norvegicus*) and Sitka black-tailed deer (*Odocoileus hemionus*) culling operations in order to demonstrate the effectiveness of these management actions. Monitoring data obtained from Kluane and Gwaii Haanas were originally used to complete status and trend assessments for these parks, and these results were compared to the park's SoPR results obtained at a later date. The results for both analyses were the same, confirming that we were calculating status and trend correctly, and the SoPR results were subsequently used.

Wherever possible, we evaluated indicators for Pacific Rim, Kluane and Kgalagadi against a standard, threshold, or target set by the park and according to the method described in Parks Canada Agency (2007a). Essentially, we assigned a value to each measure for an indicator (measures within thresholds or within one standard deviation of the mean = 2, measures in the intermediate zone or within two standard deviations of the mean = 1, and measures outside the threshold or outside two standard deviations of the mean = 0). When assigning values to each measure, we decided that an increase in the population of a 'species at risk' (used here to signify any focal species that was endangered, threatened, of concern, rare, etc.) was a positive event. When this occurred, the measure was assigned a 'green' rating as it suggested the management was having the intended outcome of increasing the abundance of that species. Although it was not an issue in this study, we acknowledge that there are examples of species (e.g., elephants, snow geese) that have exceeded the upper limit after protection measures have been established, resulting in an increased and negative pressure on the ecosystem. Likewise, because one of the common goals of managers is to decrease the stressors and threats facing the park, we decided that a decrease in the distribution or population of alien biota was a positive event. When this occurred, the measures were assigned a 'green' rating as it again suggested that management actions were having the intended outcomes or the desired status was being attained.

Table 2 – Indicators listed according to the three ecological criteria used to evaluate the effectiveness with which six national parks in Canada and Africa protected ecological integrity. 'Data indicators' reflected the concept of ecological integrity and included such things as focal species distributions, water quality, and water quantity (see text for details); these were assessed using the state of the park reports, status and trend assessment, effectiveness evaluations, or expert opinion. 'Dataless indicators' were classified as 'in progress' if monitoring or management actions were being initiated or would be in the immediate future, and as 'no data' if monitoring or management actions were not going to be initiated in the immediate future (see text for details). N = number of indicators evaluated for each park.

National Park	Criteria		
	Conservation of biological diversity	Conservation of ecosystem processes	Adaptation to and mitigation of stressors and threats
Waterton Lakes (*n* = 17)	*Cygnus buccinator*[a]; *Isoetes bolanderi*[b]; *Salvelinus confluentis*[a]; *Tympanuchus phasianellus*[a]; Grizzly Bear (*Ursus arctos*) monitoring[a]; amphibian presence/absence[a]; avian productivity[a]; ungulate monitoring[a]	Long-term average fire cycles[a]; disturbance type[c];	Non-native vegetation[a]; white pine blister rust[a]; wildlife mortality[a]; water quantity[a]; road development[a]; hydrology/water quantity[c]; climate change[c]
Kluane (*n* = 19)	Oncorhynchus nerka[a]; *Ovis dalli*[a]; *Lepus americanus*[a]; *Alces alces*[a]; Oreamnos americanus[a]; *Ursus arctos*[a]; *Tamiasciurus hudsonicus*[a]; *Spermophilus parryii*[a]; *Arctostaphylos uva-ursi*[a]; mushrooms[a]; birds[a]; mice and voles[a]	Primary productivity[c]	*Dendroctonus rufipennus*[a]; climate change[a]; recreational use[a]; Kathleen Lake aquatic system[b]; Sockeye creek water quality[b]; Dezadeash river water quality[a];
Gwaii Haanas (*n* = 26)	*Brachyramphus marmoratus*[a]; *Falco peregrinus pealei*[a]; *Eumetopias jubatus*[a]; *Haematopus bachmani*[a]; spawning pacific herring (*Clupea pallasii*)[a]; spawning salmon (*Oncorhynchus* spp.)[a]; rare vascular plants[a]; colony-nesting seabirds[a]; *Bufo boreas*[c]; *Ardea herodias*[c]	Coastal erosion[a]; coastal health assessment program[a]; forest productivity[c]	Deer culls[b]; *Odocoileus hemionus* (forests)[a]; *Odocoileus hemionus* (non-forested)[a]; Raccoons (*Procyon lotor vancouverensis*) on Seabird Island[b]; rat culls[b]; non-native vegetation (forests)[a]; forest insects and disease[a]; non-native mammals[a]; non-native amphibians[a]; non-native vegetation (shorelines)[a]; water quality[a]; post-establishment footprint[a]; extent of Alpine Zone[c]
Pacific Rim (*n* = 21)	*Haematopus bachmani*[b]; *Heterodermia sitchensis*[b]; *Abronia unbellata*[b]; *Haliotis kamtschatkana*[b]; *Eumetopias jubatus*[c]; *Brachyramphus marmoratus*[c]; forest biodiversity plots[c]; rockfish (*Sebastes* spp.)[c]; eelgrass (*Zostera marina*) beds[c]; forest songbirds[c]		Water quality (airport, Esowista, landfill creek, golf course, sewage lagoon)[c]; *Hedera helix*[a]; *Cytisus scoparius*[a]; *Ammophila breviligulata*[a]; *Nuttallia obscurata*[a]; *Ceratostoma inoratum*[a]; northern abalone (*Haliotis kamtschatkana*) poaching[a]
Kruger (*n* = 40)	*Lycaon pictus* (nos of packs)[b]; *Lycaon pictus* (pack size)[b]; Panthera leo (TPC1a=33%popl'n deviation)[b]; Panthera leo (TPC1b=16%popl'n deviation)[b]; *Diceros bicornis*[c]; *Adenium swazicum*[c]; *Siphonochilus aethiopicus*[c]; fish assemblages[c]	Fire intensity TPC1a, b,c[b]; fire pattern TPC2[b]; heterogeneity/homogenization TPC[c]	*Tarebia granifera*[b]; *Bryophyllum delegoense*[b]; *Opuntia stricta*[b]; *Harrisia martinii*[b]; *Parthenium hysterophorus*[b]; *Pistia stratiotes*[b]; *Salvinia molesta*[b]; *Eichhornia crassipes*[b]; *Opuntia imbricata*[b]; *Thelechitonia trilobata*[b]; *Arundo donax*[b]; *Austrocylindropuntia cylindrical*[b]; *Acacia decurrens*[b]; Anthrax[b]; Rabies[b]; Lion (Panthera leo)Tuberculosis[c]; instream flow rates (Mhinga-Luvuvhu, Olifants, Letaba, Sabie, Crocodile)[b]; water quality (Luvuvhu, Olifants, Letaba, Sabie, Crocodile, Shingwedzi)[b];
Kgalagadi (*n* = 23)	*Ardeotis kori*[b]; *Antidorcas marsupialis*[b]; *Oryx gazella*[b]; Panthera leo[b]; *Taurotragus oryx*[b]; *Alcelaphus buselaphus*[b]; *Struthoi camelus*[b]; *Polemaetus bellicosus*[b]; *Connochaetes taurinus*[b]; *Sagittarius serpentarius*[b]; *Raphicerus campestris*[b]; *Acinonyx jubatus*[c]; *Felis lybica*[c]; *Crocuta crocuta*[d]; *Panthera pardus*[d]; *Hyaena brunnea*[d]	Fire cycles[c]	*Rhigozum trichotomum*[b]; *Argemone ochroleuca*[b]; *Prosopis glandulosa*[c]; *Schinus molle*[c]; *Salsola kali*[c]; *Galinia africana*[c]

TPC = Threshold of potential concern.
a Data indicators = state of the park report.
b Data indicators = status and trend assessments, effectiveness evaluations, expert opinion.
c Dataless indicators = indicators 'in progress'.
d Dataless indicators = indicators designated as 'no data'.

Table 3 – Total number and type of 'data indicators' and 'dataless indicators' used in an initial assessment of six case study national parks in Canada and South Africa. 'Data indicators' reflect the concept of ecological integrity and were assessed using the SoPRs, status and trend assessment, effectiveness evaluations, or expert opinion. 'Dataless indicators' were classified as being 'in progress' or as having 'no data' (see text for details).

		National Parks					
		Canada				South Africa	
		Waterton Lakes	Kluane	Gwaii Haanas	Pacific Rim	Kruger	Kgalagadi
Data indicators	State of the parks report (SOPR)	12	15	19	–	–	–
	Status and trend assessment/ effectiveness evaluation	–	–	0	6	16	10
	Expert opinion/secondary data	–	3	3	9	18	3
Dataless indicators	Indicators 'in progress'	5	1	4	6	6	7
	Indicators with 'no data'	–	–	–	–	–	3
Total number of indicators		17	19	26	21	40	23

If one-third of the measures for an indicator were rated as '0', the status of an indicator was classified as poor; otherwise, indicator status was calculated as the sum of the measure scores divided by the number of measures and then multiplied by 50 (Parks Canada Agency, 2007a). These indicator values were then assigned a status colour according to Table 3. All remaining indicators were designated either as being 'in progress' if monitoring or management actions were being initiated or would be in the immediate future, or as having 'no data' if monitoring or management actions were not going to be initiated in the immediate future. Broadly, we use the term 'data indicators' if the indicators were evaluated using the SoPRs, status and trend assessments, effectiveness evaluations, or expert opinions, and 'dataless indicators' if they were designated as either 'in progress' or 'no data. The total number and type of indicators assessed for the parks are listed in Table 3.

Table 4 – Cumulative indicator status scores and associated colour (Parks Canada Agency, 2007a). Scores for indicator status were calculated as the sum of the individual measure scores divided by the number of measures and then multiplied by 50 (see text for detail).

Indicator scores	Status colour
67–100	Green
34–66	Yellow
0–33	Red

The monitoring data for the following types of indicators could not be evaluated using the Parks Canada Agency (2007a) method: water quantity and quality, fire management, and alien biota. Instead, we used available monitoring data and developed an evaluation for each indicator as follows. In Kruger, data were obtained for minimum and drought instream flow rates for the park's major river systems. We considered each river to be a separate indicator, with several sampling sites along that river being the measures. We first assigned a value to each measure for each site along a river using the following: measure is above the minimum flow rate = 2, measure is located between the instream and drought flow rate = 1, measure is below the drought rate = 0. The status of each site along a river was then calculated as the sum of the measure scores divided by the number of measures and multiplied by 50 (Parks Canada Agency, 2007a). Scores for each site along a river were averaged to obtain a total effectiveness score for that river, and assigned a status colour according to Table 4.

The water quality data used for Pacific Rim consisted of raw data for a variety of elements (e.g., phosphorous, iron) and components (e.g., pH, conductivity) from several sampling sites within a specific region (e.g., airport, golf course) of concern to the park. These were evaluated using percent compliance against the *Working Water Quality Guidelines for British Columbia* (Ministry of Environment, Lands and Parks, 1998). Data points were separated for each sampling site (e.g., Esowista Tributary and Esowista Creek) for the same region (e.g., Esowista) according to year and element or component being measured. If the data point was within the limit, it was rated as 100% compliant; if it exceeded the limit it was rated as 0% compliant. Scores for all elements or components measured at a sampling site were averaged to obtain total site compliance. Total site compliances for all sample sites in a region were then averaged according to year, and this final percentage was assigned a status colour according to Table 4.

Water quality data for Kruger extended from November 2003 to December 2006 and were in the form of graphs depicting one of the elements or components being measured at each site. These were evaluated using percent compliance against the specific water quality guidelines identified in Venter (unpublished data). Data points were separated for each site along the same river according to year and element or component being measured. If the data point was within the limit, it was rated as 100% compliant; if it exceeded the limit it was rated as 0% compliant. Data points for each element or component were summed and averaged for each sampling site to determine the total site compliance. All of the sites along a river were then summed and averaged to produce a total score for the entire river system. As with Pacific Rim, these final percentages were assigned a status colour according to Table 4.

Kruger had identified three *Thresholds of Potential Concern* (TPCs) for fire intensity and one TPC for fire pattern in the park. Using these TPCs as the upper and lower limits, the location of each measure was evaluated in relation to the TPC. For instance, TPC 1a states that the TPC limit for each fire intensity class is: <20% or >50% of the area burnt for each class. The following status colours and values were designated for each measure: 0–10% of the area burnt for each class = red (0), 10–20% = yellow (1), 20–50% = green (2), 50–75% = yellow (1), >75% = red (0). The scores for the measures within each TPC were multiplied by their value, summed and divided by the number of measures and then multiplied by 50 (Parks Canada Agency, 2007a). These scores were then assigned a status colour according to Table 4.

Some of the stressors and threats facing the Kruger were evaluated using meeting minutes from the park's *Conservation Services Management Committee*. Progress was tracked for 15 alien or invasive species and three diseases (bovine tuberculosis in lions (*Panthera leo*), anthrax, and rabies) from 2004 until mid-2007. (The park's invasive species biologist agreed that 2004 onward was representative of park efforts to curb invasive alien plant threats (L. Foxcroft, 28 August 2007, pers. comm.)). If the threat was removed from the TPC list or was considered to be under control due to a management action, it was designated a 'green' status. If management actions were continuing and the threat was less than a Level 1 TPC (see SANParks, No Date), it was considered to be a concern and was designated a 'yellow' status. If the threat was ongoing or increasing or if it was a Level 1 TPC, it was designated a 'red' status. The interpretation of these results were reviewed and agreed to by the invasive species biologist at Kruger (L. Foxcroft, 16 May 2007, pers. comm.).

Finally, if park managers or biologists felt confident providing their expert opinions and qualitative judgements, these were used to designate status for the remaining indicators according to a more nuanced effectiveness rating scale (Table 5). On this scale, a score of two or three was considered 'effective'. Experts were asked to err on the side of caution and provide conservative estimates, opinions or qualitative judgements of status; hence, these were likely lower than the actual status of the indicator concerned.

Table 5 – Rating scale for determining protected area management effectiveness in which a rating of '2' or '3' denotes effectiveness (adapted from Arias and Valery, 1999). These scores were used for any assessment that relied exclusively on the expert opinions or qualitative judgements of park managers or park biologists.

Rating	% of optimum	Colour	Effectiveness description
3	76–100	Dark green	Very satisfactory
2	52–75	Light green	Satisfactory
1	26–51	Yellow	Dissatisfactory
0	0–25	Red	Very dissatisfactory

2.4.1.2. *Determining indicator trend.* If a case study park had prepared a SoPR, its trend results were used. For all other parks, the Parks Canada Agency (2007a) method was followed. Essentially, this method evaluates whether the current status of the indicator has crossed a threshold and rates it accordingly (e.g., red–yellow = increasing trend, green–red = decreasing trend). If the status of the indicator had not changed but one-third or more of the measures were declining, it was assigned a declining/decreasing trend. This scoring system is more sensitive to declines in the ecological integrity of measures than to no change or increasing status (Parks Canada Agency, 2007a). The final level of evaluation subtracted the number of declining measures from the number of increasing measures and, if the net number of changing measures was greater than 2 or less than −2, the indicator was designated a trend reflecting the more abundant group of changing measures. Otherwise, it was designated as having no change.

For several indicators (e.g., water quality, instream flow rates) it was not possible to determine a present trend because of insufficient historical data. If park managers or biologists felt confident providing their expert opinions and qualitative judgements, these were used to designate trends for the remaining indicators, using the scale shown in Table 5. For any remaining indicators, the trend was designated as "unknown". Trends for water quality data from Pacific Rim were determined by graphing the average compliance for each year at each site, and reading a linear trend line for these data. A trend was not assigned for the indicators designated as 'in progress' or 'no data' in the status assessment.

2.4.2. *Converting indicator ratings into numerical values*

Once a status and trend had been determined for each indicator, they were converted into numerical format using the scale shown in Table 6.

Table 6 – Scale used to convert status and trend into a numerical format. Status is the relationship of the current state of a measure and an identified threshold or target. Trend marks the change in the ecological integrity status of an indicator from a previous status, and was recorded as increasing, stable, decreasing, or unknown change. 'Unknown' trend means there were insufficient historical data to determine a present trend.

Status	Trend	Numerical value
GREEN	Increasing	12
	Stable	11
	Decreasing	10
	Unknown	9
YELLOW	Increasing	8
	Stable	7
	Decreasing	6
	Unknown	5
RED	Increasing	4
	Stable	3
	Decreasing	2
	Unknown	1

2.4.3. Incorporating similar indicators into broad indicator categories

For this study, it was necessary to ensure the results of all park evaluations were as comparable as possible. To do this, we combined similar indicators into broader categories for each park. For example, in the Kruger we combined 15 indicators of alien biota into the same general indicator category, while in the Kgalagadi we combined six antelope indicators into the same general indicator category. Parks Canada based its assessments of ecological integrity on the major ecosystems within each park (Parks Canada Agency, 2007a), and within each of these major ecosystems (e.g., wetlands, lakes, streams, forest, non-forest), the specific indicators of each park were combined. For example, a broad 'forest' indicator for one park could include evaluations of deer density, vegetation, invertebrate and bird communities. The total number of indicators used to calculate the effectiveness with which ecological integrity was protected for each park is listed in Table 7.

2.4.4. Calculating the effectiveness with which ecological integrity was protected

The effectiveness with which the ecological integrity of each park was protected was calculated in two steps. First, parks were evaluated against how well they performed on the 'data indicators'. This involved only those indicators derived from SoPRs, status and trend assessments, effectiveness evaluations, or expert opinion. In other words, this analysis was based only on those indicators for which the parks had monitoring data. Second, parks were evaluated against how well they performed on all of their identified indicators, including the 'dataless indicators' that had been designated as 'in progress' or 'no data'. By incorporating the 'data indicators' and 'dataless indicators' into the second analysis, the overall score took into account failures (for whatever reason) to collect the necessary information. The information about 'dataless indicators' is an important part of the analysis as while managers may receive good scores based on the data indicators they choose to prioritize, the indicators that they have identified as important but are failing to monitor may be equally important. In some cases, these indicators may be more difficult (or more expensive) to monitor, but as they are identified as important to the overall management objectives, the lack of data should be considered as reducing the effectiveness of the management and scored accordingly.

2.4.4.1. Calculating how effectively ecological integrity was protected using 'data indicators' only. Parks were evaluated against how well they performed on 'data indicators' by dividing the total numerical score that a park achieved on its 'data indicators' (above) by the total potential score the park could have achieved on those indicators (calculated by multiplying the number of indicators included in the 'data indicator' phase by 12, the highest score possible). A high quotient demonstrates that the park achieved a high score proportionate to the score that could have potentially been achieved, and was performing well on the priorities for which they had monitoring data. These scores were then multiplied by 100% to determine percent effectiveness achieved, and were designated an effectiveness description, rating, and colour using the ordinal rating scale in Table 5.

2.4.4.2. Calculating how effectively ecological integrity was protected using all ('data' and 'dataless') indicators. Parks were evaluated against how well they performed on all of their identified indicators, whether monitoring data were available or not. Each indicator was weighted in the following manner: indicators from the status and trend assessment = 1, indicators in progress = 0.5, indicators not in progress = 0. The weight for each criterion's indicators were summed and divided by the total number of indicators for the park to get a weighted value. This weighted value was multiplied by the total numerical score the park achieved on its 'data indicators', and was then divided by the same total potential score the park could have achieved on those indicators (as calculated above). A high quotient demonstrates that the park achieved a high score proportionate to the score that could have potentially been achieved, and was performing effectively overall even though some indicators were lacking monitoring data. Based on the results of this calculation, an overall

Table 7 – Total number and type of 'data indicators' and 'dataless indicators' assessed to calculate the effectiveness with which ecological integrity was protected by six case study national parks in Canada and South Africa after combining similar indicators (e.g., alien biota) into common groups. 'Data indicators' reflect the concept of ecological integrity and were assessed using the SoPRs, status and trend assessment, effectiveness evaluations, or expert opinion. 'Dataless indicators' were classified as being 'in progress' or as having 'no data' (see text for details).

		National Parks					
		Canada				South Africa	
		Waterton Lakes	Kluane	Gwaii Haanas	Pacific Rim	Kruger	Kgalagadi
Data indicators	State of the parks report/ status and trend assessment/ effectiveness evaluation/expert opinion/secondary data	12	16	15	8	8	7
Dataless indicators	Indicators 'in progress'	5	1	4	6	6	4
	Indicators with 'no data'	–	–	–	–	–	3
Total number of indicators		17	17	19	14	14	14

effectiveness score was determined for each park. These scores were then multiplied by 100% to determine the percent effectiveness achieved, and were designated an effectiveness description, rating, and colour using the ordinal rating scale in Table 5.

2.4.5. *Sensitivity analyses*

The classification of a few indicators under a particular criterion was considered subjective for two parks: Waterton Lakes and Kluane. A sensitivity analysis was performed on these parks to determine how much the overall criterion and park effectiveness scores would change if one or more indicators were moved to a different criterion. For both parks, climate change was moved to *Ecosystem Processes* from the *Stressors and Threats* criterion. For Kluane, Kokanee Salmon (*Oncorhynchus nerka*) was also moved from the *Biological Diversity* criterion to *Ecosystem Processes* as it is an important component of the Kathleen watershed aquatic ecosystem (Parks Canada Agency, 2007b). We then repeated the calculations to determine how effectively ecological integrity was protected using all indicators.

A second sensitivity analysis was performed in regard to indicators that did not have trends. If it was not possible to determine a trend for an indicator, the trend was originally listed as 'unknown'. The corresponding numerical score (Table 6) that would be attributed to an indicator with an 'unknown' trend was lower than if any trend (including a decreasing trend) had been determined, thus a sensitivity analysis was performed whereby the 'unknown' trends were scored in the middle of the category instead of at the bottom. We then repeated the calculations to determine how effectively ecological integrity was protected.

3. Results

Parks that received effectiveness descriptions of 'very satisfactory' or 'satisfactory' (Table 5) were considered effective at maintaining ecological integrity. When the parks were analysed using only the 'data indicators', three parks (Gwaii Haanas, Kruger, Kgalagadi) received scores indicating they were 'satisfactory' or 'very satisfactory' overall at addressing ecological integrity (Table 8). However, the effectiveness rating of each park decreased when all (both 'data' and 'dataless') indicators were included in the analysis. This indicates that the parks had generally identified more priority indicators than they were actually able to address (for whatever reason, including lack of budget or trained staff, managerial challenges).

In all parks except Kluane, scores for the 'data indicators' decreased when 'dataless indicators' were incorporated into the analysis of the *Conservation of Biological Diversity* criterion. Kluane maintained the same overall rating of 'satisfactory' for both types of indicators because there was monitoring data to address all indicators. The Kruger's decrease between the two types of indicators was the most pronounced, with a change from 'very satisfactory to 'very dissatisfactory' (a decrease of 66%), because four of the six indicators in this criterion were 'in progress'. The Kgalagadi's score also had a sharp decrease from 'very satisfactory' for the 'data indicators' to 'dissatisfactory' for all indicators because five of the park's 11 indicators were designated as either 'no data' or 'in progress'. Waterton Lakes maintained 'satisfactory' ratings for both analyses, while scores for both Gwaii Haanas and Pacific Rim decreased after incorporating the 'dataless' indicators into the analysis.

Park performance on the *Conservation of Ecosystem Processes* criterion was generally very poor for each of the case studies. Three parks (Kluane, Pacific Rim, Kgalagadi) had no monitoring data for indicators within this criterion, resulting in scores of 0% (a 'very dissatisfactory' rating). Waterton Lakes received 'very dissatisfactory' ratings for both types of indicators because one of the two indicators was in progress and the other 'data' indicator (long-term average fire cycles) received a 'very dissatisfactory' score. The decrease in the scores for Gwaii Haanas and the Kruger can be partly explained by one-third of their indicators being 'in progress'.

Kluane and Pacific Rim maintained the same score across both types of indicators within the *Adaptation to and Mitigation*

Table 8 – Overall score and individual criterion scores (displayed as a percentage) for 'data indicators' and all ('data' and 'dataless') indicators for how effectively the six national parks protected ecological integrity. The hatching follows the colour system described in Table 5.

	Conservation of biological diversity (%)		Conservation of ecosystem processes (%)		Adaptation to and mitigation of stressors and threats (%)		Overall effectiveness at protecting ecological integrity (%)	
	Data	All	Data	All	Data	All	Data	All
Canada								
Waterton Lakes	74	61	17	6	52	23	48	30
Kluane	69	69	0	0	67	67	45	45
Gwaii Haanas	65	47	71	39	73	56	70	47
Pacific Rim	44	12	0	0	56	56	33	23
South Africa								
Kruger	88	22	50	28	73	53	70	34
Kgalagadi	81	28	0	0	83	31	55	20

of Stressors and Threats criterion as each park had monitoring data for all indicators. Both parks received a 'satisfactory' rating for their four indicators. The ratings for the other four parks decreased when all indicators were analysed compared to when only 'data indicators' were analysed. The Kruger maintained a 'satisfactory' rating across both types of indicators as it performed well on three of the four 'data' indicators and had only one indicator 'in progress'. In comparison, the Kgalagadi's rating for this criterion decreased substantially from 'very satisfactory' (83%) to 'dissatisfactory' (31%) because one of the two alien biota indicators was 'in progress'.

A sensitivity analysis was performed on Waterton Lakes and Kluane to determine if the overall criterion scores would change if one or more indicators were moved to a different criterion. For Waterton Lakes, climate change was moved to *Ecosystem Processes* from the *Stressors and Threats* criterion. The score for all indicators in the *Ecosystem Processes* criterion decreased to 4% (from the previous 6%), while the score for the *Stressors and Threats* criterion increased from 23% ('very dissatisfactory') to 29% ('dissatisfactory'). Despite the changes in the criterion scores, the overall effectiveness rating for the park remained unchanged. Two indicators were changed for Kluane: Kokanee Salmon and climate change were moved from the *Biological Diversity* and *Stressors and Threats*, respectively, to *Ecosystem Processes*. Several scores changed when the calculations were repeated. If only Kokanee Salmon was moved to *Ecosystem Processes*, the score for all indicators within *Ecosystem Processes* increased to 6% (from 0%) but the criterion rating remained 'very dissatisfactory' (while ratings remained the same, the actual scores within a rating class could have changed). If only climate change was moved to *Ecosystem Processes* from *Stressors and Threats*, the scores for both criteria increased but the ratings remained unchanged. However, if both climate change and Kokanee salmon were added to *Ecosystem Processes*, the score for *Ecosystem Processes* increased from 0% to 19% (but remained 'very dissatisfactory') and the ratings for *Biological Diversity* and *Stressors and Threats* remained the same. Despite changing the criterion under which these indicators were located, the overall effectiveness rating for each park remained unchanged.

A second sensitivity analysis was performed to determine how park effectiveness scores would change if those indicators with 'unknown' trends were reattributed with scores in the middle of the category instead of at the bottom (see Table 6). This reattribution of scores was only required for a very limited number of indicators in a few of the case studies. The reattribution of scores did not affect the overall criterion ratings though the individual scores may have changed a small amount.

4. Discussion

Each of the national parks included in this study had a management plan which provided often detailed information about identified issues of concern the park managers were attempting to monitor. However, data were not being collected on all of the indicators associated with these concerns and the overall effectiveness score for each park decreased when the parks were analysed using all (both 'data' and 'dataless') indicators as compared to when they were analysed using only the 'data indicators' (Table 8). Only Kluane maintained the same score across both analyses as park managers had collected monitoring data for all but one of their indicators (Table 8). This decrease in scores could be attributed to the time frame of the assessments. By this we mean that the data indicators (e.g., species counts) generally reflect current (or even past) levels, whereas the dataless indicators (e.g., climate change) generally project forward to issues that are increasingly becoming a concern. Because of this, it is not surprising that the analysis of all ('data' and 'dataless') indicators show a bleaker picture, and emphasizes that evaluations of park effectiveness ought to be standardized over a set time period.

These results also raise several important issues about the indicators used in the management of national parks. While the indicators we evaluated in this study were explicitly identified, it is questionable whether these were actually the managers' highest priorities. There are at least three types of indicators park managers can monitor:

(1) those that are the easiest to monitor but are not necessarily the most informative ecologically;
(2) those that are the most important to understanding park ecological integrity; and
(3) those that are monitored more because of the intended audience than for their ecological value as indicators (such as 'charismatic megafauna').

While we believe most of the indicators evaluated in this study adequately reflect the ecological integrity of the individual case studies, we must also question whether there are other potential indicators of ecological integrity that the parks have not used. To carry out a complete analysis on this front would require a detailed evaluation of the ecological integrity literature, which is beyond the scope of this paper. However, it is worth mentioning here that managers could opt to monitor indicators that are easiest to detect changes in, or that reflect their management efforts, rather than those that reflect ecological integrity, *per se*.

One such indicator that has not been monitored by most of the case studies, in spite of its potentially catastrophic impacts, is climate change. Like several other stressors and threats that are beyond local park management control, there could be ways to manage the impacts of climate change in parks. However, doing so requires sound data on indicator status and trends, and may indeed require an understanding of the cause-effect relationships between actual management actions and the indicator. In some cases, this can only be determined through an experimental approach, often involving ecosystem manipulations. Such studies may be beyond the resources of some parks, may be contrary to the regulations governing the management of the park, or may be contrary to the assumption that protection alone is the only management action appropriate for a national park. In this study, the vast majority of indicators were evaluated using a status and trend assessment. Kruger was the only park with a few indicators amenable to an evaluation of the effectiveness of *management actions*.

At the outset of the study, we anticipated two results. First, we postulated that there could be a need to question the relevance of the selected indicators to ecological integrity within each park. Potential indicators for evaluating ecological integrity in national parks have been identified elsewhere (Timko and Satterfield, 2008), and the study presented here enables us to assess how comprehensively the case studies addressed those potential indicators. While the case studies do well in regard to monitoring for the *Biological Diversity* criterion, several appear to fail in respect to monitoring a robust set of indicators for the *Ecosystem Processes*. In particular, the case study managers have neglected to assess herbivory and predation, disturbances, and productivity as appropriate to their parks. While Waterton Lakes, Gwaii Haanas, and Kruger have begun to address several of these types of indicators, Pacific Rim, Kluane and the Kgalagadi have not established robust monitoring programs for them. Several of the cases studies also lack indicators in regard to *Stressors and Threats*. It has already been mentioned that climate change monitoring in most of the case studies is lacking. Depending upon the individual context of each park, park managers may also want to pay particular attention to the following gaps in their monitoring programs: insularization and fragmentation (for Pacific Rim, Kruger and the Kgalagadi), illegal hunting (for Waterton Lakes, Kluane, Gwaii Haanas, Kruger, and the Kgalagadi), disease and pest epidemics (for Pacific Rim and the Kgalagadi), and pressure and incursions from external sources (for Gwaii Haanas, Pacific Rim, Kruger and the Kgalagadi). In general, most of the case studies have addressed water quality/aquatic contamination and diseases and pests within this criterion.

We also postulated that national parks with comprehensive management plans and explicit management objectives would have more robust monitoring programs, better data sets, and would be the most ecologically effective overall. This was not necessarily the case for the parks included in this study. Waterton Lakes, Kluane, and Kruger had comprehensive management plans with explicit management objectives and readily available data sets for the analyses required in this study. Kluane received a 'satisfactory' rating overall, partly due to the fact that most of the park's identified priority indicators were being monitored and had data available. Waterton Lakes was one of the most ecologically ineffective parks overall when all indicators were analysed, and the Kruger demonstrated the largest decrease between the analyses for the 'data indicators' and all indicators. Comparatively, the management plan for Gwaii Haanas did not have explicit management objectives, yet the park managers had completed a SoPR, had readily available data sets, and the park received a higher rating overall than either Waterton Lakes or Kruger.

There were a number of ways in which we could have influenced the results of this study. The classification of some of the indicators under a particular criterion could have been considered subjective, although our sensitivity analysis demonstrates that relocating these indicators would not have influenced the overall park effectiveness scores. The most obvious example is with the 'climate change' indicator. Because both of the parks in which this dilemma was present were managed by Parks Canada and had an SoPR, we deferred to the indicator assignations in those reports. Thus, we elected to locate this indicator in the *Stressors and Threats* criterion instead of *Ecosystem Processes*; however it could be argued that climate is an important ecosystem process. The rating scale used for this research (Table 5) appeared logical and reasonably straightforward to use (Salafsky and Wollenberg, 2000). However, there is always a risk associated with the use of expert opinion data given the different perceptions and experiences of these individuals. What for one respondent may seem 'satisfactory' may be 'dissatisfactory' for another. For the parks where expert opinion was used, overall effectiveness scores could have been higher than those found in this study because respondents were asked to err on the side of caution when providing their opinion on status and trend designations. Finally, we assumed that each criterion was equally important to a park's ecological integrity, and that each indicator was equally important within a given criterion. As such, we attributed an equal weight to each. Further research into the relative importance of each of these and other criteria and indicators to the ecological integrity of parks could inform this weighting and emphasizes the importance of maintaining a dynamic effectiveness evaluation strategy in order to respond appropriately to individual park circumstances.

5. Conclusions and recommendations

National parks and protected areas are amongst our best current options for maintaining and enhancing biodiversity, if we manage them within the 'matrix' of uses across a landscape and with consideration for shifting climatic conditions and atmospheric pollution (Noss, 2001; Lindenmayer and Franklin, 2002). Yet, the conservation of biological diversity and ecosystem processes in national parks is challenged by threats and stressors both internal and external to parks. Park managers need to better understand the status of ecological integrity within their parks, and to subsequently determine if selected management actions are resulting in desired outcomes. The integration of monitoring, evaluation and reporting into the cycle of park management can generate informed feedback that enables managers to learn from and improve on past management approaches and so progressively improve management effectiveness.

The case study approach was used to evaluate how effectively six national parks in Canada and South Africa protected ecological integrity. While several parks were effective at addressing the priorities for which they had monitoring data, none of the case studies were considered ecologically effective when all (both 'data' and 'dataless') indicators were included in the analysis. This demonstrates that while the parks effectively addressed indicators for which they had monitoring data, the park managers had generally identified more priority indicators than they were actively monitoring. Yet this should not be seen as a negative result by any means. It demonstrates that the case study park managers continue to monitor indicators of biological diversity (e.g., species) but have also identified current and pressing concerns that will require attention either immediately or in the near future. Climate change is a good example of a concern that will continue to challenge management efforts in national parks and protected areas. Once they have identified pressing concerns, managers must then initiate well-designed monitoring programs to address these concerns. A systematic evaluation, such as the one employed in this study, should be considered for evaluating these monitoring data.

Below, we provide several recommendations for park managers to consider as they attempt to maintain or restore ecological integrity in parks. These recommendations are separated into two types: general recommendations to be considered by all national park managers, and specific recommendations for the managers of the case study parks involved in this study.

5.1. *General recommendations*

(1) A systematic approach similar to the one used in this study for evaluating ecological integrity in national parks is recommended, as protected areas managers cannot be expected to conserve the biological diversity and ecosystem processes within their borders if they are unaware of the ecological status of the park's biodiversity.

(2) Park managers should consider pursuing two types of monitoring programs: monitoring the status of ecological integrity in the park, and monitoring that will assist managers in evaluating the effectiveness of their management actions. The difference in scores for the analyses of 'data indicators' and 'all indicators' in this study demonstrates that managers in these parks have not collected monitoring data for all of their identified priority ecological indicators. We recommend that managers start modestly by actively monitoring a core group of indicators that reflect the park's ecological integrity. Managers can then establish monitoring programs for new concerns, and for determining the effectiveness of any management actions.

5.2. *Park-specific recommendations*

(1) The case study managers have generally neglected to assess indicators of *Ecosystem Processes*, such as herbivory and predation, disturbances, and productivity. While Waterton Lakes, Gwaii Haanas, and Kruger have begun to address several of these types of indicators, Pacific Rim, Kluane and the Kgalagadi have not established robust monitoring programs for them.

(2) Several of the cases studies lack indicators in regard to *Stressors and Threats* (in particular, climate change monitoring is lacking in most of the case studies). Depending upon the individual context of each park, park managers may also want to pay particular attention to the following gaps in their monitoring programs: insularization and fragmentation (for Pacific Rim, Kruger and the Kgalagadi), illegal hunting (for Waterton Lakes, Kluane, Gwaii Haanas, Kruger, and the Kgalagadi), disease and pest epidemics (for Pacific Rim and the Kgalagadi), and pressure and incursions from external sources (for Gwaii Haanas, Pacific Rim, Kruger and the Kgalagadi).

(3) For the Kruger, the scores for the instream flow rates and water quality should be considered important findings to the park managers because the spatial configuration of the park is sub-optimal for the conservation of riverine biodiversity as the major rivers flow into and out of the park rather than being contained within the park (Roux et al., 2008).

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