Ecological Monitoring: A Vital Need for Integrated Conservation and Development Programs in the Tropics

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Abstract: The integration of conservation with rural economic development is the latest proposed means of preventing loss of the earth’s biodiversity and of solving the dilemma of “people versus parks.” International development agencies now recognize the need to preserve natural resources and biodiversity in concert with improving human well-being; likewise, conservation agencies acknowledge that parks cannot be protected over the long term without the consent and support of local inhabitants. Nonetheless, of 36 integrated conservation and development projects (ICDPs) reviewed by us and others, only 5 demonstrate that they have positively contributed to the conservation of wildlife. In this paper we promote ecological monitoring to (1) evaluate the ICDP paradigm and specific ICDPs, (2) provide feedback to guide the future course of ICDPs, and (3) integrate information relevant to both conservation and development. Few ICDPs have included ecological monitoring programs to date, although several have plans to monitor in the future. We outline a flexible blueprint for ecological monitoring of ICDPs and provide an example from our ongoing work in Madagascar. To establish comprehensive ecological monitoring programs, we recommend that two types of monitoring be carried out at multiple levels of ecological organization and across diverse taxa. First, monitoring programs should assess the total effects of ICDPs on biodiversity and on overall ecosystem health by tracking indicator assemblages across space and through time (biodiversity monitoring). Second, ICDPs should monitor the resources and

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ecological processes that will be directly affected by changes in human activities due to implementation of ICDPs by comparing target species diversity and abundance in unregulated areas, managed buffer zones, and core protected areas through time (impact monitoring). Comprehensive ecological monitoring is critical in shaping ICDP management plans and in furthering the integration of conservation and development.

Introduction

Over the past decade, a new paradigm for the protection of natural areas has emerged, one that attempts to integrate sustainable land and resource use with conservation of biotic diversity (Goodland, 1987; Shaffer & Satterson 1987). Worldwide, increased demands for natural resources by a burgeoning human population have pressed even marginal lands into use, at the inevitable expense of local, regional, and global environmental quality (Ehrlich 1971). Conservation of global biodiversity seems unattainable unless human resource consumption diminishes globally and sustainable use strategies are implemented locally (McNeely 1988). Herein lies the motivation to develop sustainable economic alternatives to habitat destruction and to integrate them with conservation efforts in areas where substantial biodiversity still remains.

In general, the goal of integrated conservation and development programs (ICDPs) is to promote conservation of biodiversity while improving human living standards. The mechanism is to provide local people with environmentally sound, economically sustainable alternatives to destructive land use. However, the hypothesis that rural development can promote conservation of biodiversity remains virtually untested. ICDPs are still in their infancy, but available evidence suggests that ICDPs are not yet effective in protecting biodiversity. For example, of 36 ICDPs reviewed by us and others (Brown & Wyckoff-Baird 1992; Wells et al. 1992), just five were able to show a positive relationship between development efforts and conservation of endangered biological resources. Of the many inherent assumptions and problems that plague the integrated conservation and development paradigm, chief is the notion that well planned rural development will automatically lead to conservation successes (see Robinson 1993). Often the linkages between development and conservation in many “integrated” programs are far too diffuse to ensure success.

Of importance to achieving ICDP goals is recognition that biodiversity means different things to different people and interest groups—biologists, planners, government officials, and rural development experts. We define biodiversity as the composition of natural variation found in genes, species, communities, and ecosystems (Wilson 1988). Protection of biodiversity requires more than short-term maximization of species richness in protected areas: it also requires maintenance of the complex genetic and ecological fabric of biological elements that interact at different hierarchical and functional levels (Noss 1990). Managed landscapes can provide habitat for a wide diversity of species (Pimentel et al. 1992), but many species cannot be supported in such environments. Thus even moderate human use of environments can modify them sufficiently to lead to biotic impoverishment (Nepstad et al. 1991). We agree with Robinson (1993) that sustainable development “while improving human life . . . will inevitably decrease the diversity of life.” Integrated conservation and development projects must therefore recognize that development will come at some cost to biodiversity in these managed landscapes and must ensure that adequate regions of unmodified habitat are protected (Noss 1991).

Equally, a pure preservationist view is not viable in much of the world; hence the goal of retaining all existing biodiversity and restoring ecosystems to their original pristine conditions is unrealistic (Cairns 1988). The strongest strategy for maintaining biodiversity is still to integrate conservation and development. Therefore, conservation biologists should invest substantial effort to improving the integrated conservation and de-
velopment model so that these projects will accomplish their stated goals. Ecological monitoring is critical to this process, to both evaluate ICDPs and provide information to adapt and improve management strategies. Unfortunately, despite the millions of dollars spent on ICDP implementation, few projects have included adequate ecological monitoring programs (Table 1). Indeed, the need for monitoring and evaluation of ICDPs has only recently been recognized by the agencies funding these projects (Brown & Wyckoff-Baird 1992; Wells et al. 1992; Global Environment Facility Guidelines of the International Union for the Conservation of Nature, unpublished); therefore, only recently have some projects proposed monitoring for future phases of their work.

Our view, based on experiences in tropical conservation, is that monitoring could serve as a feedback mechanism to promote better integration of conservation and development. The goal of this paper is to suggest a flexible blueprint for monitoring programs that integrate conservation and development. While recognizing the need to integrate socioeconomic and ecological mon-

### Table 1. Ecological monitoring programs of integrated conservation and development projects (ICDP).

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<td><strong>ICDPs Providing Economic Alternatives Within Reserves</strong></td>
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</table>

*a None = no ecological monitoring currently in place.

*b Impact = monitoring of target resources.

*c Comprehensive = both biodiversity and targeted monitoring.

*d Proposed = future phases of the project will include ecological monitoring.

References: individual ICDP reports to various funding agencies; (1) Kiss 1990; (2) Wells et al. 1992; (3) Brown and Wyckoff-Baird, 1992; (4) project reports; (5) authors' personal knowledge.
toring for complete ICDP evaluation, we restrict this paper to ecological monitoring of natural biological communities.

**Integrated Conservation and Development Projects**

Sustainable development practices of ICDP projects fall into two general categories: (1) those that provide direct incentives for conservation of biodiversity through the harvest of animal or plant resources that are found in and are dependent upon natural habitats in protected areas (for example, direct revenue sharing from hunting wildlife in Zimbabwe; see Murindagomo 1989) and (2) those that provide access to alternative or better resources outside of protected areas (such as intensified rice production on converted lands outside national parks in Madagascar). These two development strategies operate on different principles to promote the conservation of biodiversity. Existing natural habitats, available material resources, and human cultural attributes together determine the appropriate strategy for integrated conservation and development.

**ICDPs Promoting Economic Alternatives within Reserves**

Of the more than 36 ICDPs reviewed by us and others (Wells et al. 1992), the five projects that appear to be achieving their stated conservation goals (Table 1) depend on natural areas for generating revenue; they therefore have community-driven incentives for protection of these areas. For example, strictly enforced quotas on wildlife hunting in Africa successfully ensure that target species are conserved as valuable biological resources (Murindagomo 1989; Lewis et al. 1990). In these and other ICDPs, local residents are motivated to conserve the natural habitats on which the resource depends, as is the case for wildlife ranching (Robinson & Redford 1991), traditional agro-ecosystems using native plants (Altieri et al. 1987) and ecotourism (Vedder & Weber 1990).

ICDPs with such incentives show a clear link between conservation and economic development, but there are several inherent limitations to the applicability of this type of ICDP. Harvested resources must be renewable, yet maximum sustainable yields are difficult to determine, and many industries have failed to achieve the goal of sustainability despite considerable expense and effort (Ludwig et al. 1993; Safina 1993). In addition, it is not enough to consider solely the effects of harvesting on utilized species; sustainable harvesting can produce cascading ecological effects that alter ecological communities over time (Nepstad et al. 1991; Robinson 1993). Thus, harvesting strategies and ecotourism should be strictly limited to multiple-use zones, so some areas of "pristine" landscape or wilderness can be maintained as core protected areas (Noss 1991). We recommend that ICDPs that rely on sustainable extraction heed the warnings of Robinson (1993), who suggests that managers monitor both the species being harvested and the ecological communities that harbor them.

**ICDPs Providing Economic Alternatives Outside of Reserves**

Many problems accompany attempts to link the benefits of enhanced or alternative resources offered outside of reserves to conservation of biological diversity within reserves. This is because rural development programs rarely depend on the existence of biodiversity. While sustainable development requires functions of ecosystems such as nutrient cycling, hydrological dynamics, and soil stabilization, such ecosystem services need not rely on biodiversity (Schulze & Mooney 1993). For example, soils can be stabilized and enriched for agriculture by cultivation of nonnative nitrogen-fixing species. This promotes valued services for agro-ecosystems but reduces biological diversity through the homogenization and simplification of habitats (see Janzen 1986).

Even ecosystem services that depend on forest preservation and clearly benefit local residents may provide no more than weak links between conservation and development. For instance, in the Ranomafana National Park in Madagascar, short-term benefits available from slash-and-burn farming are more important to local residents than the long-term benefits available from watershed protection (such as irrigation, power generation, and prevention of upland soil erosion and lowland siltation). Ecosystem services alone are unlikely to provide adequate incentives for conservation in ICDPs.

A further problem is that improving agricultural techniques may not reduce the need to place more land under cultivation. Increased standards of living may lead to population growth, human immigration, and the accumulation of wealth, possibly resulting in more land being placed into cultivation. Perhaps to alleviate negative environmental effects, agricultural extension projects and small enterprises should not be implemented on the reserve periphery. For those ICDPs that encourage alternative economic options outside of reserves, it is essential to monitor biodiversity rather than to assume that positive results in the development sector will lead to achievement of conservation goals.

**Designing an Ecological Monitoring Program for an ICDP**

Monitoring programs must first document the initial or baseline conditions of both natural areas and adjacent human-altered landscapes. These different types of baseline data are needed to assess the impact of the ICDP through time on both biodiversity and patterns of human disturbance. Indicators that show definitive responses to changes in human activities over time need
to be identified, and the distributions and abundances of indicator species or species assemblages should be documented across the landscape. Finally, monitoring schemes require construction of explicit testable hypotheses (Murphy 1990; Murphy & Noon 1991) in order to differentiate indicator responses to natural environmental fluctuations from responses to anthropogenic activities and to adapt management strategies to desired goals (Holling 1978; Walters & Holling 1990). Care taken in designing experimental monitoring schemes by establishing baseline data, selecting and testing indicators, and developing and testing hypotheses will allow for differentiation between meaningful and meaningless results—results often acquired at virtually the same cost and effort.

For comprehensive monitoring programs, both Noss (1990) and the Global Environment Facility (unpublished data 1992) advocate the selection of indicators that collectively represent multiple levels of organization (populations, species, communities, ecosystems, and landscapes) from structural, compositional, and functional perspectives. This diversified approach ensures perception of ecosystem responses to anthropogenic effects that occur from the landscape level (such as deforestation) down to the species level (such as hunting). To develop comprehensive monitoring programs for ICDPs, we recommend two basic types of monitoring activities: monitoring overall changes in biodiversity by using selected indicator species assemblages (biodiversity monitoring) and monitoring of human effects on target species (impact monitoring). Both types of monitoring should use rigorous experimental design to assess the effects of the ICDP; this will require monitoring in three areas—managed zones, unregulated areas, and core protected areas.

**Biodiversity Monitoring**

Biodiversity monitoring follows overall changes in community composition as surrogates for ecosystem health and thereby provides a means of tracking broad changes in biodiversity. Monitoring suites of species, rather than individual species that are the subjects of management, assists biologists in identifying ecological changes that may result secondarily from project activities. Naturally, second-order effects are difficult to predict; therefore, choosing individual target species a priori to assay for such effects is rarely possible. Therefore, it is necessary to use general monitoring methods to measure these higher order effects of disturbance and the overall influence of the ICDP on biodiversity.

An important goal of biodiversity monitoring is to provide decision-makers with quantitative before and after comparisons of the response of biodiversity to ICDP management plans. When similar population trends are observed across many taxa in apparent response to human activities, a manager’s ability to infer cause and effect, to demonstrate stasis or change, or to issue an alert (as in the case of local change in amphibian populations) is greatly enhanced.

Indicator assemblages for biodiversity monitoring should comprise diverse functional groups (Collins & Thomas 1991; di Castri et al. 1992; Kremen et al. 1994) because ecologically diverse taxa are likely to respond in different ways to the same impacts. This method confers greater sensitivity and robustness to monitoring programs (Karr 1991; Kremen et al. 1994). Changes in status of indicators (presence, abundance, health) should be simple to assay and must provide early warning of environmental change. Therefore, indicator assemblages should be pretested to assess their sensitivity and response to disturbance by conducting baseline surveys across existing disturbance gradients (Kremen 1992). Species’ associations with specific habitat types can then be established, permitting informed interpretations of long-term monitoring trends to provide greater predictive value. For example, dramatic increases in the abundance from disturbed areas species within forest-interior habitats can be interpreted as a warning signal that core areas of forest are being affected by disturbances along their borders.

The advantage of biodiversity monitoring is that it assays the ecological responses of multiple organisms with differing life histories and ecological characteristics. Biodiversity monitoring does not determine the response of specific target species, such as flagship or game species, to management techniques. In fact, biodiversity monitoring helps guard against too limited a focus on such target species, which is important given gaps in our ecological knowledge, particularly in tropical systems. Traditional monitoring programs often have been restricted to one or a few target species and have been criticized on the grounds that such exclusive focus produces management agendas that only reflect the needs of a limited species pool (Landres et al. 1988; Hutto et al. 1994).

**Impact Monitoring**

While biodiversity monitoring provides a control for examining changes in biodiversity within protected areas, impact monitoring focuses on both resources and ecological processes that are directly affected by ICDPs. Most natural areas today are islands set in human-dominated landscapes (Harriss 1984). Through protection and development activities, ICDP projects influence the amount and distribution of different land-use types and thus potentially influence interactions between humans and nature.

The balance between pristine natural areas and anthropogenically disturbed areas influences all manner of ecological phenomena, including fragmentation and
edge effects, invasion of natural areas by nonnative species, regeneration of natural communities, and ecosystem processes, such as nutrient and water cycling, energy flows, and soil production and stability. Conservation and development activities may also affect traditional human patterns of resource use, including hunting, fishing, and gathering. Monitoring the effects of humans on natural areas and the manner in which these effects change with ICDP implementation can provide valuable insights to guide the ICDP process, for both conservation and development sectors.

In many projects, the impacts that should be monitored take place within buffer or multiple-use zones. Buffer zones are the front lines for both conservation and development, where the majority of management-related activities are concentrated. These activities not only have the greatest potential for changing regional ecological equilibria, but they also can have significant economic consequences for local people. Impact monitoring thus must provide a means of gathering and integrating information concerning both conservation and development.

For comprehensive monitoring programs, the potential effects of human activities on various ecological processes should be examined. However, few monitoring programs have sufficient financial resources to cover all possible areas of concern. Each ICDP should include target monitoring programs most pertinent to its local and regional environmental problems. Several brief hypothetical and real examples of impact monitoring are described below.

HABITAT FRAGMENTATION

Human colonization and expansion have resulted in fragmentation of the natural communities that harbor the majority of the world’s biodiversity. The precise pattern of converted lands and remaining natural areas often determines where conservation and development efforts should be focused. For example, habitat corridors may be important for species migrating between forest patches (Forman 1991). Through satellite imagery, the only narrow corridor of forest connecting two large parcels of forest on the Masoala Peninsula of Madagascar was identified. This forest corridor is not accessible by road, and its existence would have remained unknown without landscape-wide monitoring tools such as satellite imagery. This potentially vital forest connection is in imminent danger of being severed by slash-and-burn agriculture. In light of the possible importance of such a corridor, this corridor of forest has been designated as a priority for immediate protection. Development activities will be focused on alleviating slash-and-burn agriculture around the corridor. Monitoring changes in habitat fragmentation patterns and remaining forest cover is one of the simplest ways to monitor changes in biodiversity and ecological health. All else being equal, the number of species and the size of populations is usually positively correlated with overall area and configuration of natural habitat (Wilcox & Murphy 1985).

EDGE EFFECTS

Physical conditions along habitat edges can influence the environment far into the interior of core protected areas. Edge conditions can alter the distribution and abundance of interior-dwelling species, allow for invasions by exotic species, and result in secondary effects from changes in community composition (Harris 1984; Janzen 1986; Lovejoy et al. 1986; Wilcove et al. 1986). Many biological responses to edge conditions are mediated by microclimatic shifts in light, temperature, relative humidity, and wind (Chen et al. 1990, 1992). Also, edge effects can vary dramatically according to patch size and to the tilt and azimuth of the edge (Wales 1972; Murphy & Austin, unpublished data). If edges are to be created, management options to reduce the ecological impact of edges should include careful design and pre-selection of sites according to an allowed set of physical conditions (slope, aspect, elevation, and topography) and mitigation of edge effects by management for “soft edges” (planting of wind-breaks or feathered cuts; Weiss & Murphy 1993). Monitoring conditions that result from these and other management options require the selection of indicator species or assemblages that are sensitive to edge effects (Sisk & Margules 1993). Changes in these species distributions then can be used as metrics for comparing biological responses to different management options.

HARVEST OF RESOURCES

Identifying and quantifying harvested species, as well as characterizing the areas in which they are taken, constitutes baseline information for selection of target species. Target species can then be used to monitor human effects and the manner in which these change with ICDP implementation. It is important to determine whether current rates of harvest constitute threats to those species and whether harvesting of those species results in secondary effects for the ecosystem. It would be ideal to determine sustainable harvest levels for all harvested species; unfortunately, this is extremely difficult to do, especially for typically understudied tropical species (Robinson & Redford 1991). If the linchpin of a successful ICDP is sustainable harvest of wildlife, then biological research efforts must focus on the collection of data necessary to determine sustainability of the most vital resources (Murindagomo 1989). Such impact monitoring has been implemented in a number of ICDPs that provide economic alternatives within reserves (Table 1). More commonly, however, local residents harvest
hundreds of species for various uses, rendering all-inclusive impact monitoring impossible and providing another argument in favor of concurrent biodiversity monitoring. Those species that are most intensively harvested or that may be keystone species in the natural community should be selected as target or indicator species for impact monitoring in both multiple-use zones and core areas.

**ECOSYSTEM PROCESSES AND SERVICES**

Healthy ecosystems provide diverse services that influence both converted and natural habitats, such as maintenance of soil and water quality and of climatological, nutrient, and hydrological cycles (Ehrlich & Mooney 1983). Ecosystem data can be used to monitor the effects of human disturbance on a landscape scale and to adapt management plans accordingly (Hornbeck & Swank 1992; Swanson & Franklin 1992). Hornbeck and Swank (1992) used watershed ecosystem analysis, based on calcium input and losses to the system, to identify forest cutting regimes that could be sustained in forest patches with different land-use histories. Studies of a similar nature should be designed to evaluate the effects of various management regimes on biodiversity. For example, inputs of woody debris and other sediments influence the quality of stream habitats, which in turn determines the composition of aquatic communities. Because ecosystem processes directly affect the success of both conservation and development efforts, incentives for monitoring ecosystem processes will arise from both conservation and development components of ICDPs.

**EXOTIC SPECIES**

Invasive exotic species often accompany human immigration, cultivation of alien crops, and grazing of domestic animals. To evaluate the relative effects of exotic species, research and monitoring should document distributions of exotic species and their effects on the composition, structure, and function of ecosystems. Eradicating detrimental exotic plants from protected areas is a common conservation management strategy that is labor-intensive and requires an accompanying monitoring program. This is especially true for small reserves, which are particularly vulnerable to invasions because of high edge-to-area ratios and because they can quickly be overridden by alien species (Abbott 1992). In Berenty, Madagascar, where exotic parasitic plants have spread extensively and strangled much of the native foliage, managers have intermittently tried to control the invasion by mechanical removal. But without data on the spread of these plants, it is impossible to assess the effectiveness of the eradication program.

### The Masoala Peninsula: A case study

Few integrated conservation and development projects currently conduct “comprehensive monitoring programs” (see Table 1) that meet the following criteria: (1) recognize the need for monitoring at multiple levels of ecological organization (species, communities, ecosystems, and landscape; Noss 1990); (2) monitor for changes in composition, structure, and function within natural systems (Franklin 1988); (3) include the use of indicator assemblages representing diverse taxa (di Castri et al. 1992; Kremen et al. 1994); and (4) include both generalized biodiversity monitoring that assesses overall regional changes in biodiversity across space and through time, and impact monitoring that evaluates the influence of the ICDP on the species most likely to be directly affected by human activities.

We are currently designing such a program for the Masoala Peninsula in Madagascar (Table 2). The Masoala

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<th>Hierarchical Level</th>
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Peninsula supports a largely undeveloped humid rain forest that spans nearly 300,000 ha in northern Madagascar. This forest currently has no formal protected status. The Masoala ICDP (jointly developed by CARE-International Madagascar, Association National pour la Gestion des Aire Protegées, Direction des Eaux et Forêts, and the New York Zoological Society/The Wildlife Conservation Society) plans to establish a national park and associated buffer zones. Many of the project’s development activities will be conducted within these buffer zones that will embrace forested regions surrounding the park. Sustainable, community-based forest management plans are to be developed and implemented by village associations within buffer zones. Currently, villagers extract a multitude of plants and animals from the forest and the sea, but existing rates of resource extraction are neither controlled nor likely to prove sustainable. Working in three of the eleven watersheds on the Peninsula, implementors of the ICDP will begin to develop pilot conservation and development projects.

Sites for biodiversity monitoring will be selected in managed buffer zones (within pilot study watersheds), in unmanaged buffer zones (outside pilot watersheds), and in the core protected area. By studying the species compositions of indicator taxa (birds, butterflies, and small mammals) and plant community composition and structure in the three areas through time, the following necessarily simple null hypotheses will be tested:

1. \( H_0 \): No difference in biodiversity (as measured by the composition and structure of the indicator assemblages) exists between managed and unmanaged buffer zones.

2. \( H_0 \): No change in biodiversity (as recorded in the composition and structure of indicator assemblages) is found in the core areas of the park over time.

Data bearing on these hypotheses will allow managers to conclude whether the ICDP has neutral, positive, or negative effects on biodiversity in the core protected areas and buffer zones.

Additional impact studies will consider the influences of harvesting (hunting, fishing, and gathering) on forest and marine ecosystems. Target species are being chosen for population studies. The red-ruffed lemur (\textit{Varecia variegata rubra}) is an obligate frugivore and, as one of the largest mammalian seed-dispersers in the Malagasy forest ecosystem, an important mobile link species (\textit{sensu} Gilbert 1980). On the Masoala Peninsula, its population viability is potentially influenced not only by hunting but also by selective harvesting of fruit trees upon which it feeds. Ongoing studies now monitor these effects on lemur populations in exploited and less disturbed areas. Future studies of red-ruffed lemur populations will compare the effects of unregulated human disturbance, including logging, with those of managed logging in buffer zones.

The monitoring program also examines the trade-offs between the use of forest versus marine resources. Marine resources currently appear to be dwindling in the bays and lagoons of the Peninsula (F. Odendaal & V. Razafimahatratra, personal communication 1993). Use of forest resources by villagers may increase to compensate for the loss of valued marine resources. The Masoala ICDP may in turn influence the balance of forest versus marine resource use through the promotion of economic alternatives or restriction of access to certain resources. Village residents have been interviewed in a baseline survey designed to assess current forest and marine resource use. Such studies will be repeated in the future to examine the influence of ICDP activities on resource use.

Finally, to assess forest degradation at the landscape level, satellite photos will be taken every two years. Table 2 summarizes the Masoala monitoring program and indicates the extent to which it meets the criteria defined above for comprehensive monitoring programs. Similar tables that characterize monitoring in terms of taxonomic coverage, field methods, geographic location, and hierarchical rank can be useful for identifying gaps in ICDP monitoring programs. It is evident from Table 2 that the Masoala ICDP, as currently conceived, still is missing studies of the genetic and ecosystem level.

**Conclusions**

Integrated conservation and development programs provide an attractive new paradigm for biodiversity conservation as well as new sources of funding for conservation from international development assistance agencies. This new paradigm is perhaps one of our last and most promising hopes for protecting beleaguered natural areas. Nonetheless, such programs are complex and difficult to implement due to the inherent problem of reconciling the fundamentally different goals of conservation and development. Integrated conservation and development strategies may not succeed without increased efforts to include ecological and socioeconomic monitoring as assessment tools and as guides for refining management plans. Monitoring programs that provide feedback between the conservation and development components of programs can also help to ensure that objectives on both sides remain compatible. Unprecedented rigor in the design, implementation, and interpretation of ecological monitoring will be essential to provide the necessary guidance. We call on conservation biologists to work toward the successful integration of conservation and development programs by championing the need for biological and socioeconomic mon-
itoring and by creating effective, informative ecological monitoring protocols.

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