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# Conservation and management-oriented ecological research in the coastal zone of Baja California, Mexico

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**Abstract.** This paper presents the main results of two studies of contrasting natural and man-induced conditions along the Pacific coast of Baja California (Mexico), based on the assumption that ecological insight can be obtained from man-induced modifications insofar as relevant activities are explicitly addressed as parts of the systems under study. The study is concerned with a fragmented coastal succulent-sage scrub and showed that several patches of different size and age may harbor as many species as non-fragmented areas, and that 83 % of the original species assemblage persisted in the fragments, in which the invasion by opportunistic exotic species may not progress beyond certain limits. The study on dune-backed and urban-backed beaches showed a significantly greater abundance of the Snowy Plover (*Charadrius alexandrinus*) at the dune-backed beach, where a much more active back-shore feeding of adult birds and the only evidences of breeding occurred. Both studies refer to landscape features of regional concern and its results may be used in conservation management. The results on fragmented coastal succulent-sage scrub may encourage alternative urban designs that keep patches of the original landscape, thus meeting existing requirements of low density urban development for most of the coastal succulent-sage scrub area. The evidence presented on the negative effects of dune destruction on the abundance, feeding and reproductive performance of a threatened bird species has a bearing on the topic of biodiversity management. It may also contribute to the conservation of the coastal dunes system.

**Keywords:** Biodiversity; *Charadrius alexandrinus*; Ecological impact analysis; Natural experiment; Touristic development; Urban development.

## Introduction

Urban and tourist development is progressing very rapidly in Baja California, the northern state of the Baja California peninsula (Mexico) Ð which also includes the state of Baja California Sur. During the first 15 years after the completion of the transpeninsular highway, tourism, sport-fishing, hunting, whale-watching and traffic increased with 100 - 160% in the whole peninsula (Kramer & Migoya 1989).

Human activities causing major modifications of natural landscapes impose a great pressure on ecologists in their efforts to address environmental questions at the proper scale (Brown 1994). Setting and scheduling of development projects obey social needs that leave little space for further environmental evaluations (Panayotou 1993).

Although major environmental modifications occur at a scale which is beyond the physical and ethical possibilities of any scientific experiment, current applied approaches propose that ecological insight can be obtained and used in management insofar as relevant activities are explicitly addressed as parts of the systems under study (Anon. 1986; McDonell & Pickett 1990; Brown 1994). These approaches stem from the ÔNatural ExperimentÕ concept (Connell 1975), which was originally applied to large-scale scenarios differing in one key element independent of research manipulation, but otherwise alike.

Treating a project or action as an experiment can be an aid in designing a programme of monitoring effects, which in turn can be applied to the detection of unexpected outcomes, the correction of procedures, and the improvement of the planning and design of future projects or actions (Anon. 1986). This type of approach is being applied to the development of conservation biology for regions where small, highly fragmented natural habitats are typical rather than exceptional (Schwartz 1997).

In this paper we present the main results of two studies of contrasting natural and man-induced conditions imposed by development projects which affected two regional landscape features of regional concern, i.e. coastal sage-succulent scrub and coastal dune systems, and which were treated as natural experiments. In each case, the ecological topics at stake are made explicit, and the way in which the results may be brought into management is discussed.

## The study area

The study sites are located in the Tijuana-Ensenada Coastal Corridor, which extends 140 km south from Tijuana, a major city on the border with California, to the Punta Banda peninsula (Fig. 1). Previous regional land-use studies of the coastline have set the marine and terrestrial limits of the coastal corridor at 5.5 km seaward and 2 - 10 km inland, thus defining a 600-km$^2$ terrestrial domain in the coastal zone, in which major land-use changes occur (Gomez-Mor'n 1994).

The climate is Mediterranean: semi-arid, with warm dry summers and a rainy season between November and March (Walkowiak & Solana 1989). The average rainfall is 250mm/year. There is virtually no permanent runoff, although semi-catastrophic rainy seasons may occur (Anon. 1994). Main watersheds are critical during these flooding periods. The Tijuana river watershed is particularly relevant at a regional level as it is shared by Mexico, that holds 75%, and the USA, where the river flows into the Pacific Ocean (Dedina 1995). Sea water is rather cold (14-20 °C) due to the influence of the California Current (Bakus 1989). Although not particularly suitable for swimming, the impressive beauty of the coastline attracts numerous tourists the year round, mainly from the State of California.

The dominant terrestrial vegetation is coastal sage-succulent scrub. Riparian tall shrubs and mesophyllous trees grow along creeks, gullies and ravines. Sandy beaches, rocky shores and shingle beaches as well as cliffs and coastal dunes occur along the coastline. Towards the south end, the Corridor is limited by Estero Punta Banda, a coastal lagoon, and by Punta Banda, an impressive rocky promontory (Gomez-Mor'n, op. cit.) The whole area is located along the Pacific Flyway, a mayor shore-bird migratory route (Gustaitis 1993).

Between 1980 and 1990, the population growth rate in the region was no less than 4.4% per year . The major cities are Tijuana, Ensenada and Rosarito. About 75% of the tourist accommodation of the state of Baja California is concentrated in the above-mentioned Corridor, which received 17million tourists only during 1990 (Bringas 1993).

Environmental problems existing in the area can be classified in two main groups: (1) those related to water (water supply, waste-water treatment) and (2) release of pollutants into coastal waters and those related to direct impact on the natural landscape.

Management-oriented research is being carried out to assess the impact of coastal activities on ongoing aquaculture programmes (Orozco-Borb—n et al. 1994; Lizarraga-Partida & Vargas-C‡rdenas 1996). Crucial issues for future development such as water supply,

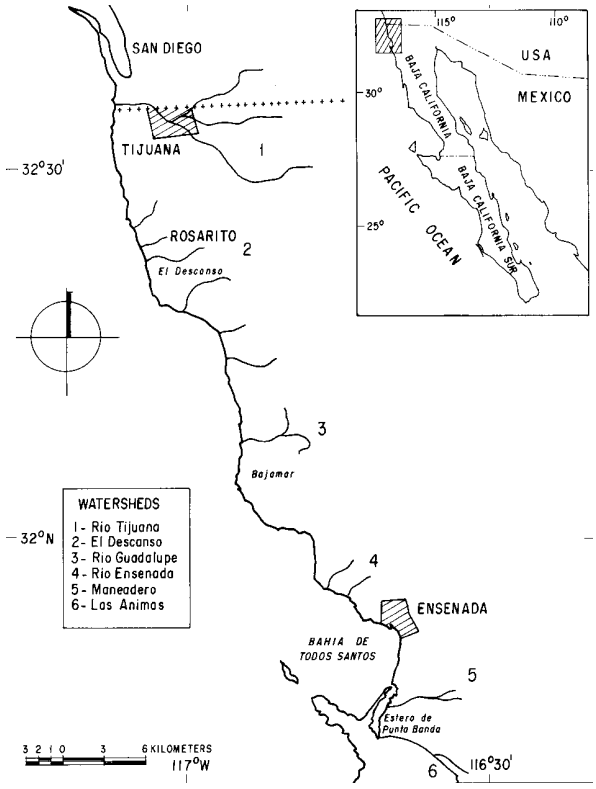


**Fig. 1.** The study area.

waste-water treatment and waste transport by oceanic currents are being considered by a series of binational approaches (Leon & Robles 1994; Crane & Pombo 1996).

At present, ca. 20% of the terrestrial natural landscape, mainly coastal sage-succulent scrub, have been either removed by urban development or replaced by agriculture. Almost 50% of the original coastal dune system has been destroyed for building purposes. Existing coastal dunes are being affected by uncontrolled off-road vehicle traffic, which eliminates the vegetation cover, or by replacement of native vegetation by exotic species (Gutierrez 1997). Studies on creeks, gullies and ravines along a urban-rural gradient on the coastal corridor show the existence of up to 60% of introduced vegetation as well as large amounts of garbage at urban ends, whereas at rural spots natural vegetation is still dominant and garbage is much less noticeable (I. Espejel unpubl.).

## Case studies

Two case study are presented: natural landscape fragmentation and irreversible loss of landscape features. Fragmentation of coastal sage-succulent scrub was studied at Bajamar, halfway between Tijuana and Ensenada; coastal dunes destruction was studied at

**Fig. 2.** Punta Banda sand spit site without dunes (**left**) and with dunes (**right**).

Punta Banda estuary sand spit. (Fig. 2). A summary of the cases is presented in Table 1.

*Fragmentation of coastal succulent-sage scrub*

*Background and field evidence*

The coastal succulent-sage scrub is an endangered community in California, USA (OÕLeary 1989). Along the Tijuana-Ensenada coastal corridor, it is rapidly being replaced by agricultural and urban landscapes (Espejel & Ojeda 1995).

In order to document the ecological effects of the fragmentation of the coastal succulent-sage scrub, a field study was conducted from 1991 to 1993 (Leyva 1995) to compare a control, non-fragmented area with a ca. 400-ha area in which two conditions existed: (1) patches of natural vegetation interspersed among the greens of a golf course that was being built (new patches); (2) patches of natural vegetation amid houses and gardens at two small urban spots built 20 years ago (old patches) (Fig. 2).

The species composition and abundance of vascular plants were recorded using the Braun-Blanquet phytosociological method (Westhoff & van der Maarel 1978) in the three types of patches: 11 quadrats in old patches, 23 in new patches, 10 in control patches. The longest axis of the patches varied between 30 and 80 m. Percent cover was measured in 10-$m^2$ subquadrats, which size corresponds to the minimum area for coastal sage as estimated by Cruz-Alonso (1997)

In total 108 species were found: 65 in the control area, 83 in new patches and 60 in old patches. Direct gradient analysis (Whittaker 1967; Keddy 1991) was employed to obtain a summary of the species ordering along the fragmentation gradient.

Arrangement of species in terms of their presence along the fragmentation gradient showed that 10.7% occurred only in the control area, 19.6% were common to the control and new patches, 33.3% were common to the three types, 16.6% occurred only in new patches, 11.7% were common to new and old patches, and 13.7% occurred only in old patches (Table 2). Further calculations revealed that 83% of the species found in the non-fragmented patches (including 81% of the native species, the six endemic species known from the area, and all the shrubs that determine the coastal succulent scrub physiognomy) were also present in the fragments (20 species in the new fragments only; 34 species in both the new and old patches).

**Table 1.** Main features of the two case studies.

| Case example | Current ecological topics | Results; management | Benefits to conservation |
|---|---|---|---|
| Fragmentation of coastal sage-succulent scrub | Island biogeography theory<br><br>SLOSS dilemma | A number of fragments of different sizes and age harboured and maintained over time 80 % of the original species assemblage | Some degree of protection of native plant diversity can be achieved through alternative urban designs maintaining patches of natural landscape |
| Destruction of coastal dunes | Gradient paradigm; Urban-rural gradient | Abundance and overall performance of the Snowy Plover, a threatened bird species, was significantly lower at the urban-backed beach | Widens support for protective management of coastal dunes by bringing the dune conservation issue into the field of biodiversity |

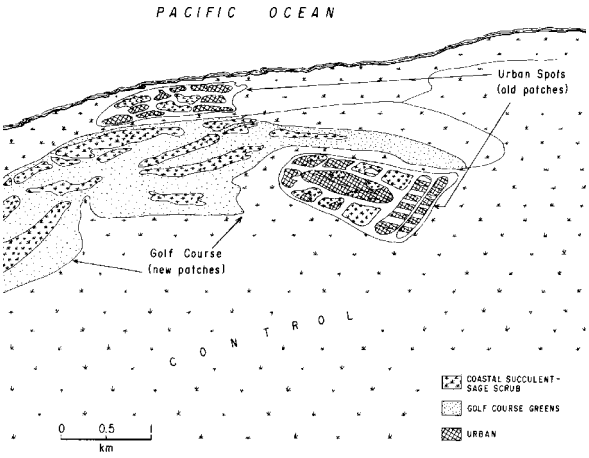


**Fig. 3.** Fragmentation of coastal sage-succulent scrub at Bajamar: a summary of field conditions.

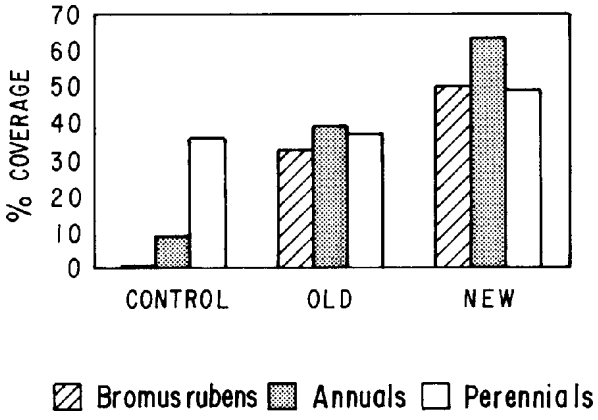


**Fig. 4.** Coastal sage-succulent scrub: relative abundance of *B. rubens*, annual and perennial species at each condition.

Arrangement of species in terms of their abundance along the fragmentation gradient showed variations which are described for the top three species: 1. *Bromus rubens*, a European species, exotic in California, and proven to be highly opportunistic after disturbance of the coastal succulent-sage scrub (Minnich 1994) was abundant only in fragments, independently of their age. 2. *Agave shawii* and *Eriogonum fasciculatum*, which are characteristic native species of the coastal succulent-sage scrub, were more abundant in old patches and in the control, respectively (Table 3). Perennials accounted for 35-50% coverage in all conditions whereas annuals had 40-65% coverage in patches and only 10 % in the control. *Bromus rubens* accounted for most annuals in the fragments, with no presence in the control (Fig. 4).

**Table 2.** Coastal sage-succulent scrub: arrangement of species in terms of their presence along the fragmentation gradient.

| Control (65 spp.) | New patches (83 spp.) | Old patches (60 spp.) |
|---|---|---|
| 11 species exclusive | | |
| 20 species | | |
| 34 species shared | | |
| | 17 species exclusive | |
| | 12 species shared | |
| | | 14 species exclusive |

As a result of composition and abundance of species, as well as the proportion of annuals and perennials, the values of S¿rensenÕs Index of Similarity among conditions changed according to the assemblages being compared: 0.46 to 0.77 when all species were included; 0.13 to 0.69 when only the annuals were considered; 0.66 to 0.89 when only the perennials were included, and 0.73 to 0.98 when only species shared by all conditions were considered (Fig. 5).

*Ecological topics*

This study addresses the issue of species abundance and composition at fragmented and non-fragmented areas. Current ecological knowledge such as the gradient paradigm (Whittaker 1967) as well as the principles of the Theory of Island Biogeography (Mac Arthur & Wilson 1967) and the associated SLOSS dilemma Ð ÔSingle Large Or Several SmallÕ (reserves), cf. Simberloff & Abele (1982) Ð can be explored in such scenarios (McDonnell & Pickett 1990; Shafer 1990; Pickett et al. 1994; Dramstad et. al. 1996).

In our case, the gradient paradigm was tested along the control-new patches-old patches axis. Predictions of the SLOSS dilemma can be seen in the results showing that 83% of the original species assemblage persist at a number of patches of different size and age. Principles of patch edges and patch extinction are illustrated by the results suggesting that invasion of fragments by opportunistic species may not progress beyond certain limits.

*Implications for conservation management*

Based on the endangered status of the community in California, the Land-use Program for the Tijuana-Ensenada Coastal Corridor proposed a low density ur-

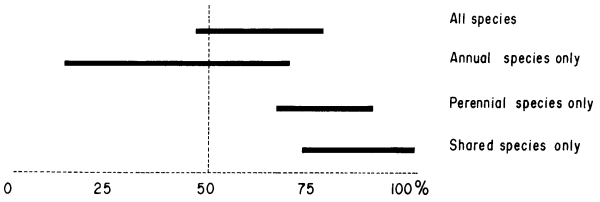


**Fig.5.** Coastal sage-succulent scrub: range of values of S¿rensenÕs Index of Similarity among patch types considering different species assemblages.

ban development policy for most of the coastal succulent-sage scrub area (Gomez-Mor'n 1994).

We found evidence that a major part of the original coastal succulent-sage scrub species assemblage may persist in a number of patches (including 81% of the native species, the six endemic species, and physiognomically important shrubs) may encourage the evaluation of alternative urban designs in which the existing natural vegetation will form part of the green areas. This in turn may discontinue the customary option of replacing natural vegetation over large areas and so meet the proposed policy.

*Destruction of coastal dunes*

*Background and field evidence*

Coastal dunes, which, in the past, were a distinctive landscape feature along the northwestern coasts of Baja California (Jordan 1951) have suffered, during the last four decades, a substantial reduction in extent, due to urban development (Gutierrez 1997). In Estero Punta Banda, 70% of the dunes along the 7-km long sand spit have been levelled for building purposes (Fig. 2). A 2.4 km long dune-backed beach remnant still stretches along the tip of the sand spit, whereas the rest has been converted into an urban-backed beach.

The Snowy Plover *(Charadrius alexandrinus*) is a small shore-bird that inhabits coastal beaches and interior alkaline lakes (Patton & Edwards 1990). On the Pacific coasts of Mexico and USA, dune-backed beaches and spits are their preferred wintering and breeding habitats (Page & Stentzel 1981; Page et al. 1986; Palacios et al. 1994). Back-shore feeding around stranded algae and marine debris is typical of adult individuals (Page & Stenzel 1981) in response to concentration of a preferred food item, a beetle species in the genus *Bledius* (Grover & Knopf 1982). The effect of different intensities of human disturbance on the density of nesting plovers has been measured on physically similar segments of coastline (Page & Stentzel 1981), but the overall population effect of the elimination of a single physical feature has not been studied.

**Table 3.** Coastal sage-succulent scrub: % cover of three main species along the fragmentation gradient.

| Species | Total | Control | Old | New |
|---|---|---|---|---|
| *Bromus rubens* | 65.0 | 0.0 | 32.5 | 32.5 |
| *Agave shawii* | 18.7 | 0.5 | 17.5 | 0.75 |
| *Eriogonum fasciculatum* | 14.5 | 7.5 | 3.5 | 3.5 |

To measure the effect of dunes elimination, a field study (Gonzalez-Yajimovich 1993) was conducted at the dune-backed beach remnant and at an equally long adjacent portion of the urban-backed beach (Fig. 6). During a 30-day period the number of individuals of the Snowy Plover along the beach profile was recorded at both sites. Feeding activity and evidences of breeding were also recorded, in order to document signs of overall performance that in the long term may influence some key population features such as individual growth and birth rates.

The number of individuals of the Snowy Plover was significantly greater at the dune-backed beach (Chi-square test, $p < 0.05$). Nests at the embryonic dunes and chicks around the backshore were recorded only at the dune-backed beach, where a much active backshore feeding of adult individuals was observed. At the urban-backed beach, besides a significantly lower number of individuals, a less active feeding of adult individuals occurred, and no signs of reproduction were found (Table 4).

*Ecological topics*

The case addresses the issue of the biological effects of urbanization on species populations. Altered reproductive status, social and behavioral changes, as well as changes in population size are to be expected in such human-induced conditions (McDonnell & Pickett 1990; Patterson et al. 1991; Powel & Cuthberf 1992). This in turn addresses the general issue of optimal and suboptimal habitats, as well as more specific concerns about the effect of physical habitat features on the abundance, habitat selection and other behavioral patterns (Anon. 1986).

**Table 4.** Observations on *Charadrius alexandrinus* over a 30-day period at the Punta Banda sand spit.

| | Dune-backed beach | Urban-backed beach |
|---|---|---|
| Number of adults | 1439 | 937 |
| Evidence of breeding | Nests at embryonic dunes; chicks at the backshore | No evidence |
| Back-shore feeding | Very active | Less active |

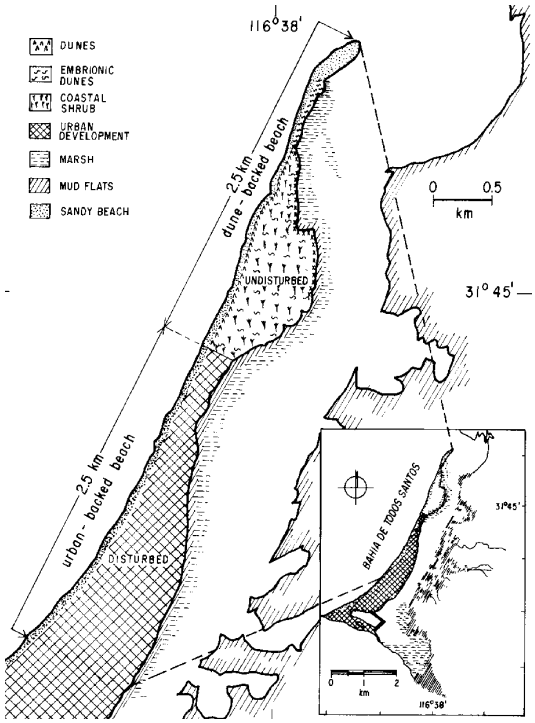


**Fig. 6.** Destruction of coastal dunes at the Punta Banda estuary sand spit: a summary of field conditions.

The dune-backed beach emerged as the optimal habitat, whereas the urban-backed beach resulted in a suboptimal habitat. The significantly greater abundance of the Snowy Plover at the dune-backed beach clearly suggests a spatial preference for the site which exhibits that physical feature. Differences in feeding activity and reproduction at dune- and urban-backed beaches, although qualitative, suggest the existence of some kind of impact on key behavioral patterns that may in the long term affect population growth and persistence.

*Implications for conservation management*

Coastal dunes are a natural shore protection, yet its destruction is a common practice hard to stop (Doody 1989; Guilcher & Hallegouet 1991; Rust 1990; van der Meulen & van der Maarel 1989).

The Snowy Plover has been categorized by the U. S. Fish and Wildlife Service as of special concern and at least locally endangered, and it is also of special concern by Mexican environmental laws. Human encroachment has caused nesting birds to disappear from many coastal breeding locations in California.

The evidence presented on the negative effects of dune destruction on the abundance, feeding and reproductive performance of a threatened bird species has a bearing on the topic of biodiversity management. It may also contribute to the conservation of the coastal dune system.

## Discussion

Coastal resource managers often need to evaluate entire coastlines, considering both ecological aspects of the environment and socio-economic requirements of the region. Methods for preliminary assessments, as well as ecologically sound data in a form useful for management, are crucial (Price 1990; Betters & Rubingh 1978). In this context, our results address both the ecologically soundness of the results, including the methodological approach, and the ecological issues considered, as well as its potential use for conservation management.

The first key step in both studies was to treat major projects as experiments, in accordance with the concept of ÔNatural ExperimentÕ (Connell 1975) and its further applications (Anon. 1986; McDonnell & Pickett 1990). The significance of large-scale changes in land-use categories is also acknowledged as a first level management criteria (Betters & Rubingh 1978).

The ecological soundness of the results can be measured by ecological features Ð with or without an impact Ð emerging from the data. The fragmentation study addresses ecological features at the community level: species richness, species composition, and resistance to invasion. The coastal dune study addresses key population responses (abundance, feeding activity, reproduction) to the presence or absence of a single physical component

The way in which our results can be applied in conservation management depends on the level of management planning and on the assessment of its suitability (Betters & Rubingh 1978). Considering that development pressure along the coast may preclude the establishment of large conservation areas, a major management decision would be whether or not the ecological vital signs detected are an acceptable contribution to environmental conservation (Schwartz 1997).

The results of the fragmentation study are similar to those of Loucks et al. (1985) in showing that 2.5-km$^2$ areas were appropriate at least for research on sand prairies dynamics, and to those by Queen & Robinson (1987) providing experimental evidence that many small reserves of the California grassland harbored a greater diversity of genetic material of flowering plants than will a few larger ones, suggest that keeping such a kind of experimental patches would be a good option for conservation management.

The results of the coastal dune study may well contribute to monitoring programs of the behavior of a threatened species population in a fragmented landscape (Robinson et al. 1997). Locally, the results strengthen the ecological significance of the tip of the Estero Punta Banda sand spit, where the single dune

remnant and a unique variety of habitats still exist, as well as a highly successful nesting colony of the Least Tern *Sterna antillarum browni* (Palacios 1992), a set of attributes that lead to consider the area for conservation, environmental education and non-manipulative research (Gomez-Mor'n 1994).

Our results have an obvious potential for research and teaching. More specific hypotheses derived from these preliminary results can be tested in the future at least as the sites are still present and monitoring programmes are set, which in turn would require major land-use decision.

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