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10-2000

Multiple Spatial Scale Assessment of Coral Reef and Hard-Bottom Community Structure in the Florida Keys National Marine Sanctuary

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Multiple spatial scale assessment of coral reef and hard-bottom community structure in the Florida Keys National Marine Sanctuary

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ABSTRACT

The zoning plan for the Florida Keys National Marine Sanctuary (FKNMS) established 23 relatively small no-fishing zones distributed mostly along the offshore reef tract in 1997. In 1999, a two-stage, stratified random sampling design based on the proportion of coral reef and hard-bottom types within the FKNMS was conducted. Our study focused on differences in coverage, density, and condition of benthic organisms with respect to habitat type, regional variations, and differences between no-fishing zones and reference sites at 80 locations spanning 200 km. Most variables exhibited significant spatial differences by habitat type or between individual no-fishing zones and reference sites (e.g. species richness, coral density, gorgonian density, and recruitment), although some regional differences were also apparent. Many of the differences among the no-fishing zones and reference sites reflect the placement of the zones in well-developed offshore reefs, and for many of the variables targeted, individual zones are as different from one another as from reference sites. These results emphasize the need to address spatial variations at multiple scales, and to consider a range of variables beyond common metrics such as coral cover.

Keywords Coral, Florida Keys, Marine reserves, Stratified design

Introduction

Like many coral reef ecosystems, the Florida Keys have experienced symptoms of "degradation" in recent decades, manifested in reported coral decline (coverage and recruitment), increases in benthic algae, severity and frequency of bleaching, disease incidence (Dustan and Halas 1987, Porter and Meier 1992), and overfishing (Bohnsack 1997). In addition, a considerable array of natural phenomena significantly affect Florida Keys reefs, in particular cold fronts because of high latitude, continental influence (Florida Bay-Atlantic Ocean exchange), destructive tropical storms, and mass mortality events, particularly to sea urchins and Acroporidae corals (Marszalek et al. 1977, Chiappone and Sullivan 1997). In response to these pressures, the Florida Keys National Marine Sanctuary (FKNMS), encompassing over 9,000 km^2, was created in 1990 to help preserve and restore this unique coastal ecosystem of the United States, while facilitating multiple uses. One of the principal features of the final management plan, implemented in 1997 after six years of public comment (Bohnsack 1997), was the creation of 23 no-fishing zones or reserves distributed mainly along the offshore reef tract.

The monitoring plan for the FKNMS zoning was designed to assess two important hypotheses related to protection from fishing: 1) fishery target species such as reef fishes (especially Serranidae, Lutjanidae and Haemulidae) and spiny lobster will increase in density and size within the no-take zones, and 2) increases in predator density and size will result in changes in benthic community structure from trophic interaction effects. The second hypothesis is the focus of the study reported here, where we provide a brief overview of the first large-scale assessment of no-take zones in the Florida Keys using a two-stage stratified random sampling design. Initial spatial patterns and prospects for detecting changes specific to zone protection in the FKNMS are discussed.

Methods

Area description

Twenty-three no-fishing zones, most one to two km^2 in area, were established in the Florida Keys National Marine Sanctuary (FKNMS) in 1997 and encompass many of the best developed offshore bank-barrier reefs, in addition to some offshore and nearshore patch reefs (Fig. 1). The zones consist of one ecological reserve (Western Sambo, 31 km^2) encompassing representative benthic habitats across the continental shelf, 18 Sanctuary Preservation Areas (SPAs, average of 0.82 km^2 in area, range of 0.16 to 3.27 km^2), and four special-use zones (Research Only, average of 1.15 km^2 in area, range of 0.68 to 1.77 km^2). SPAs are designed to protect the most sensitive and intensively used, high - relief coral reef habitat from extractive human activities. Special-use areas are limited access and are intended for research and to assess the effects of diving activities. The no-fishing zones are an important component of the management plan, and provide for the first time the opportunity to evaluate the direct and indirect effects of fishing in south Florida. The zoning strategy includes 17 of the 33 named bank-barrier reefs located 5-8 km offshore from southwest of Key West to northern Key Largo. Coral reef and hard-bottom habitat types contained within the zones include patch reefs (nearshore and offshore to the seaward edge of Hawk Channel), back reef and reef flat habitats, and the shallow and deeper fore reef (FDEP 1998).

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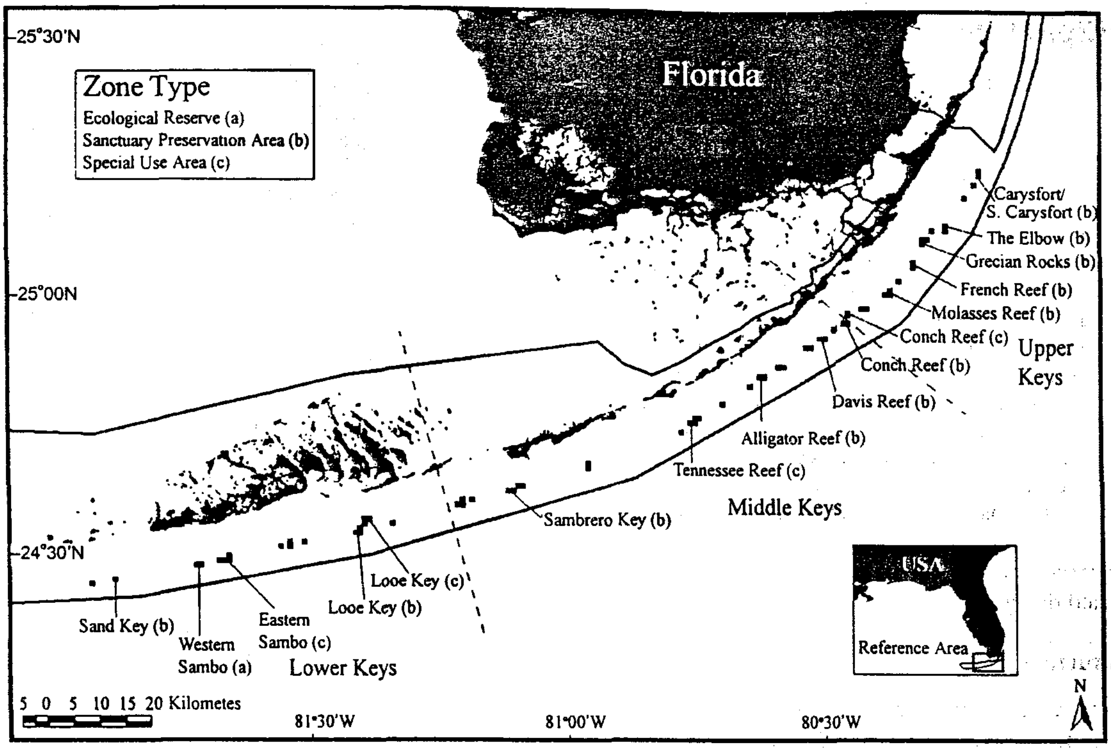

Fig. 1 Sampling locations in the Florida Keys National Marine Sanctuary during 1999 and location of 16 of the 23 no-take zones included in the study.

Table 1 Variables measured, methods used, and sample size (number of 25 m x 0.4 m transects) per site for the multiple spatial scale assessment of Florida Keys hard-bottom and coral reef habitats within no-take zones and reference areas.

Variable	Method	Sampling size (units)
Cover (*in situ*)	Linear intercept (100 points)	4 transects (% cover)
Cover (archival)	Video of 0.4 m x 25 m	4 transects
Species richness	0.4 m x 25 m transect	4 paired transects (no. species/20 m^2)
Gorgonian and coral density	0.4 m x 25 m transect	2 (no. colonies per m^2)
Coral size and condition	0.4 m x 25 m transect	2 (size distribution, condition frequency)
Juvenile coral density and size	0.65 m x 0.48 cm quadrats	10 quadrats per transect (no. juveniles/m^2)
Marine ornamental density	0.4 m x 25 m transect	4 paired transects (no. individuals/m^2)
Urchin density and size	0.4 m x 25 m transect	4 paired transects (no. individuals/m^2)

Most of the offshore zones extend seaward to only 13-15 m depth, with the fore reef usually consisting of high-relief spur and groove topography or low-relief hard-bottom from 2-8 m depth (Chiappone and Sullivan 1997) and low-relief spur and groove or low-relief hard-bottom at > 8 m depth (Shinn et al. 1989, FDEP 1998). The shallowest portions of many shallow fore reef areas were historically dominated by *Acropora palmata*, with *A. cervicornis* locally abundant in back reef and deeper fore reef areas (Dustan , Halas 1987, Porter , Meier 1992).

Regional variations in the structure and extent of patch reefs and offshore bank reefs are well known in the Florida Keys (Marszalek et al. 1977, Chiappone and Sullivan 1997), and these patterns have implications for comparing the no-fishing zones to reference sites within and among regions. These spatial variations are manifested in the size and orientation of the Pleistocene islands, and hence the degree of exchange between the Gulf of Mexico, Florida Bay, and Atlantic Ocean. In the upper Keys, the zones encompass all but one of the bank reefs with shallow spur and groove topography. A series of bank reefs with *in situ* acroporid reef flats adjacent to spur and groove topography, referred to as the inner reef line, is the location of two no-fishing zones and three reference reefs in the upper Keys. Sombrero Key is the only bank reef with shallow spur and groove topography in the middle Keys (FDEP 1998), and this is included as a zone. The remaining zones in the middle Keys are nearshore patch reefs (not designated in Fig. 1), or remnant, algal-dominated acroporid reef flats at 6-12 m depth (Shinn et al. 1989, Chiappone and Sullivan 1997). In the lower Keys, the zones encompass six of the nine bank reefs with well-developed spur and groove topography, as well as a geographically unique aggregation of offshore patch reefs north of Looe Key (FDEP 1998).

Survey methods and analyses

Because conclusions concerning the observed spatial patterns in organism densities and community structure can be affected by the scale of observation (Edmunds and Bruno 1996, Hughes et al. 1999, Murdoch and Aronson 1999), we evaluated coverage and density patterns of Florida Keys coral reef benthos among habitat types, regional sectors, and between no-fishing zones and reference areas (Table 1). The goals for sampling the response of the zones to protection from fishing focus on several questions related to spatial variability at multiple scales. First, how does the structure and condition of communities vary at regional scales, given the differences in the distribution and extent of reefs in the Florida Keys? Second, to what extent do the zones and reference sites vary, and to what degree is this related to benthic habitat type and regional setting? Third, will patch reefs, which differ in environmental setting, community structure, distance from shore, and human impacts, respond similarly to offshore reefs?

To address these questions, particularly with reference to the zone configuration scheme in the FKNMS, we employed a stratified random sampling design in 1999, following procedures discussed in Cochran (1977). Our usage of a two-stage stratified sampling design was recognition *a priori* of the advantages, especially greater efficiency, of this approach over simple random sampling. Given funding and logistical constraints, we sampled 16 of the 23 zones in the FKNMS (indicated in Fig. 1) using four habitat strata: offshore patch reef (one zone and distributed only in the lower Keys), inner reef line (one zone and distributed only in the upper Keys), shallow fore reef (4-7 m depth), and deeper fore reef (8-12 m). The allocation of sites for the shallow and deeper fore reef strata were further partitioned by regional sector: lower Keys (southwest of Key West to Big Pine Shoal), middle Keys (Big Pine Shoal to Conch Reef), and upper Keys (Pickles Reef to Carysfort Reef). Spatial areas comprising each of the sampling strata were constructed in a geographical information system (GIS) using georeferenced data on benthic habitat types (FDEP 1998). Calculations of stratum areas and random allocations of sampling stations within strata were performed with the GIS. Two study sites, each with four paired transects (see below), were allocated to each no-fishing zone by randomly selecting 200 m x 200 m blocks or sites within each habitat stratum. Reference sites were randomly assigned by habitat type (according to FDEP 1998 data) and regional sector, and a total of 80 sites spanning 200 km were sampled during September to December 1999.

A suite of variables was measured to evaluate the responses of the zones relative to reference areas (Table 1), using and modifying previous sampling procedures (Aronson et al. 1994; Chiappone and Sullivan 1997). At each site, four random sampling points using differential GPS were located. At each GPS point, two paired, 25 m transects were deployed, typically from inshore to offshore. Transects serve as the basis for measuring coverage, species richness, and the densities and sizes of macro-invertebrates. Three personnel complete all surveys, with the exception of video, using pencils and plastic slates, with a site typically taking 90 minutes to sample. We recognize that independent sampling (repeat visits based on re-randomizing sampling locations within the designated strata) makes it more difficult to detect significant temporal changes, since the spatial variance term is larger than what results from using fixed transects. An advantage, however, to using the random design is that conclusions are not bound to the particular histories of individual organisms and the specific areas of reef sampled. Further, minimum detectable differences can be calculated and modified, based on funding and input from managers.

For the 1999 sampling effort, mean coverage, densities, and species richness of coral reef benthos were compared among habitat strata, among regional sectors for shallow and deeper fore reef strata, between combined no-fishing zones and reference areas by habitat strata and regional sector, and among individual zones and combined reference sites by habitat strata and regional sector. Statistical comparisons of means were conducted by calculating confidence intervals (CI) based on the equation: CI = mean $\pm$ $t_{[\alpha,\ df]}$ *standard error. Standard errors were estimated by the two-stage, stratified random sampling design (Cochran 1977) and confidence intervals were adjusted for multiple comparisons using the Bonferroni procedure (Miller 1981). The experiment-wise error was held at $\alpha = 0.05$ and the comparison-wise error was adjusted based on the number of multiple comparisons (comparison-wise error rate = α/c, where $c = k(k-1)/2$ and k = number of comparisons).

Results

Table 2 summarizes some of the emerging patterns from the 1999 Sanctuary-wide assessment of no-take zones and corresponding reference sites. Figures 2-3 provide data visualization examples that highlight the utility of the hierarchical, stratified approach, using two percent coverage parameters (total algal cover and stony coral cover) and two species richness parameters (stony corals and sponges) for illustrative purposes. Of the 13 parameters reported, nearly half showed significant variations among the four habitat strata surveyed. Total algal cover was significantly lower on offshore patch reefs, reflecting the prevalence of sand interspersed with massive corals (Fig. 2). Habitat variability was also evident for all three species richness parameters, gorgonian density, and scleractinian coral density. Coral species richness was significantly greater on offshore patch reefs, while sponge species richness was significantly greater on both offshore patch reefs and inner reef line spur and groove (Fig. 2). In contrast, coral cover, sponge cover, juvenile coral density and urchin density (total and by species) were highly variable at this spatial scale.

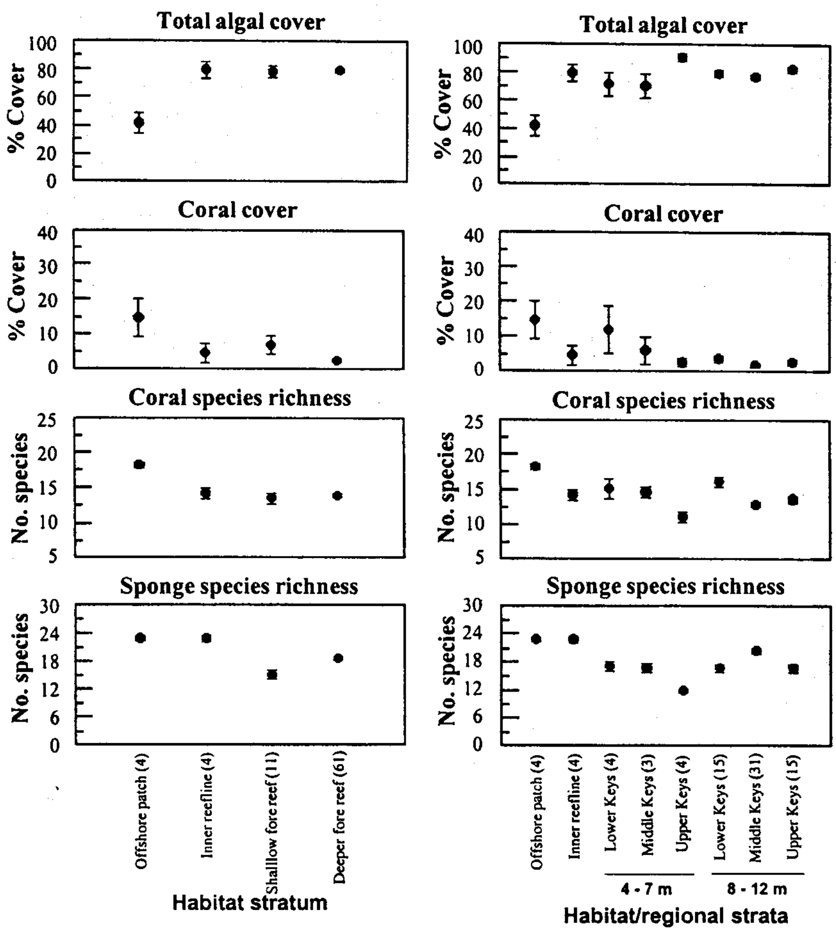

Fig. 2 Mean coverage and species richness (no. species per 20 m^2) by habitat type (left-side graphs) and habitat type and regional sector (right-side graphs). Error bars represent one standard error and numbers in parentheses are the number of sites sampled in each stratum.

Table 2 Significant differences in the mean at a given comparison-wise error rate α for Florida Keys reef benthos.

Parameter	Habitat	Habitat/region	Reserve vs. reference sites (8-12 m fore reef depth)	
			Pooled zones vs. reference	Individual zones
	(α = 0.0083)	(α = 0.016)	(α = 0.0033)	(α = 0.0024)
Percent cover				
Total algae	**			
Species richness				
Stony corals	**	**	**	**
Gorgonians	**	**	**	**
Sponges	**	**	**	**
Gorgonian density	**	**	**	**
Coral density	**	**	**	**
Juvenile coral density				**

Spatial variations by regional sector (upper, middle and lower Keys) were only significant for five of the 13 parameters (Table 2). On the deeper fore reef (8-12 m depth), for example, coral species richness was significantly lower in the middle Keys compared to the lower Keys (Fig. 2). In contrast, sponge species richness was significantly greater on the deeper fore reef in the middle Keys compared to both the upper and lower Keys. On the shallower fore reef, sponge species richness was also greater in the lower and middle Keys compared to the upper Keys.

Comparisons of benthic community structure and condition between no-fishing zones and reference sites on the deeper fore reef (8-12 m) revealed a number of significant spatial variations (Table 2). Comparisons within the deeper fore reef habitat stratum are emphasized here because of the relatively large sample size allocated during 1999. All three species richness parameters, as well as gorgonian density and coral density exhibited differences with respect to region and management type. In contrast, coverage parameters like mean algal cover and coral cover did not and were similarly high (algae 75-

80%) or low (corals < 5%). Coral species richness was significantly greater on lower Keys zones compared to middle Keys zones and reference sites, as well as upper Keys reference sites. Sponge species richness exhibited a much different pattern, with significantly greater mean values on middle Keys zones compared to both upper and lower Keys zones (Fig. 3). Sponge species richness on upper and middles Keys reference sites was also significantly greater than on upper and lower Keys zones at 8-12 m depth

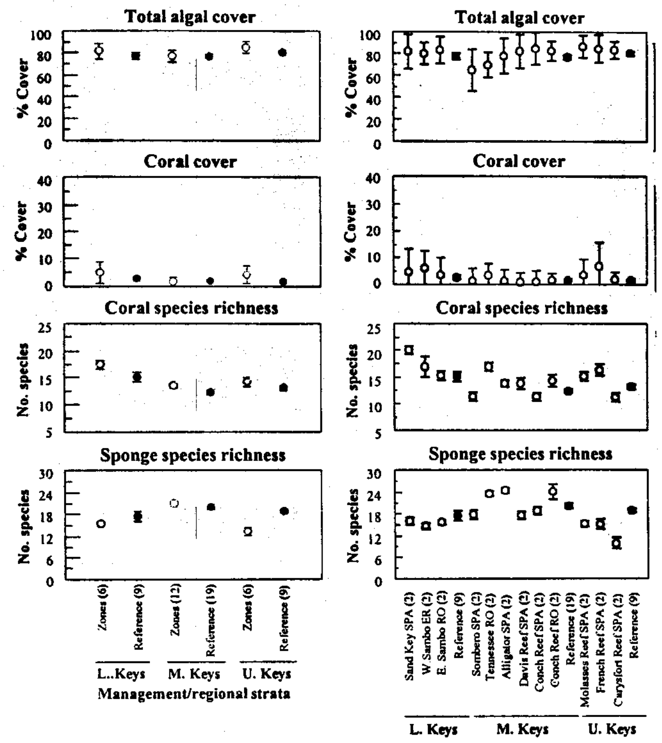

Fig. 3 Mean coverage and species richness (no. species per 20 m^2) between combined (left-side graphs) and individual (right-side graphs) no-fishing zones (open circles) and reference sites (filled circles) on the deeper fore reef. Error bars represent one standard error and numbers in parentheses on the x-axis represent the number of sites sampled in each stratum.

Another spatial scale examined was between individual no-take zones and pooled reference sites by regional sector and habitat type (Fig. 3). Six of the 13 parameters in Table 2 exhibited variation at this scale, however, none of the benthic cover variables such as total algal cover and coral cover were significantly different. Species richness varied with respect to individual zones and reference sites. Relative to reference sites, coral species richness was greater in one of three zones in the upper Keys, only one of five zones sampled in the middle Keys, and only one of four zones in the lower Keys. Sponge species richness exhibited an opposing pattern to corals (Fig. 3), exhibiting an increasing trend toward the middle Keys relative to the upper and lower Keys. In the lower Keys, no differences in species richness between zones and reference sites were apparent. In the middle Keys, two of the five zones had significantly greater species richness than reference sites, while in the upper Keys, two of the three zones had significantly lower species richness than reference sites.

Discussion

It is clear that many biological phenomena are scale dependent, conclusions can be affected by the scale of observation, and caution needs to be exercised in scaling up results from small-scale studies to spatial and temporal patterns that were not sampled (Edmunds and Bruno 1996, Hughes et al. 1999). Sampling at multiple spatial scales is usually necessary to determine whether or not patterns at one spatial scale (e.g. among transects or within an individual reef site) are indicative of regional patterns (Murdoch and Aronson 1999). The interpretation of changes or spatial patterns observed in reef community structure is also made complex by biases introduced by how sites are selected. For example, diverse and healthy reefs such as those with high coral cover, selected at the start of a monitoring program, can only remain unchanged or deteriorate once the study is initiated (McClanahan 1997). Interestingly, while no-take zones were selected based on criteria biased toward the best developed offshore reefs in the Florida Keys, results presented here document that based on measuring a full suite of community parameters, no-take zones are as likely to be as different from each other as they are from surrounding reference sites. These patterns are possibly related to differences in local history and patchy effects of stochastic events such as storm damage.

Another important factor to consider in program design is the suite of parameters included in the sampling effort. Cover and species richness are most frequently used with a focus on corals, because after all, corals are often the dominant organism or they are of high interest to managers. However, when coral cover is regionally low as it is in the Florida Keys (Figs. 2-3), and because there are so many potential indirect effects that might result from the no-fishing protection, none of which can be predicted with any degree of certainty, we decided to include the broadest possible suite of parameters in our monitoring program.

Because our monitoring program has immediate relevance to important management issues in Florida, timely production of results is a high priority. Also, the program is partly funded by the FKNMS program and it is a grant requirement to provide rapid turn-around of data. Thus, *in situ* measures are used that require personnel with specific taxonomic expertise. The advantage of this approach is that data are transferred from underwater slates to computer spreadsheets on a daily basis, with summary statistics available in a timely manner. While there are clearly good reasons to use photography, video, and permanent transects, our questions are well suited to an approach that uses rapid assessment techniques in a limited funding environment.

Results from one-year of large-scale surveys in the Florida Keys show that for the variables measured and the study questions of interest, a multiple spatial scale approach is advantageous for delimiting factors related to geomorphology, regional variations, and management regimes. In the latter instance for the Florida Keys, the patterns observed between no-take zones and reference sites are due to the initially biased site selection of the zones, and not to short-term effects of protection from fishing. Of course, this could change longer-term if expected changes occur in fish and mobile invertebrate community structure. Ongoing efforts include broader sampling to cover additional habitats, newly established reserves in the Dry Tortugas, and sampling optimization.

Acknowledgements This study was supported by the FKNMS and Emerson Associates International and conducted under permit FKNMS-074-98. The staff of SeaTow, NURC/UNCW, and The Nature Conservancy provided logistical support. The authors especially thank S. Holst, A. White, J. Ault, S. Smith, G. Meester, E. Franklin and B. Haskell. This manuscript was improved by comments from P. Edmunds and B. Keller.

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