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Multispecies survey design for assessing reef-fish stocks, spatially explicit management performance, and ecosystem condition

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ABSTRACT

Principles of statistical sampling design were used to guide refinement of a 30-year multispecies fishery-independent diver visual survey of population abundance and size structure of more than 250 exploited and non-target fishes in the Florida coral reef ecosystem. Reef habitat features and no-take marine reserves (NTMRs) were used to partition the 885 km^2 sampling domain into sub-areas (or strata) to control the variation of fish density. For the period 1999–2008, survey precision of population density and abundance (CV, coefficient of variation, ratio of standard error to mean) ranged from 7% to 20% for the majority of 13 primary exploited species in the Florida Keys and Dry Tortugas regions. Population sustainability metrics like species average length in the exploited life stage were comparable between our fishery-independent survey and fishery-dependent catch-sampling. The survey design also performed well for non-target fishes, yielding CVs between 6% and 15% for population density for the majority of 36 species. Sampling efficiency was improved over time via an iterative learning process by which past survey data was used to refine the stratification and allocation schemes of future surveys. We show how survey data are used to support multispecies stock assessments, evaluate the effectiveness of NTMRs, and assess ecosystem condition for the reef fish community.

1. Introduction

The southern Florida coral reef ecosystem supports lucrative fishing and tourism economies (Ault et al., 2005a). Fishery-dependent (FD) information has been the principal data source supporting stock assessments to address the key management objectives of preventing overfishing and sustaining benefits from tropical ecosystems with high species diversity (Pauly and Morgan, 1987; Gallucci et al., 1996; Sparre and Venema, 1998). However, there are risks in basing assessments entirely upon data from extractive fishing operations (Walters and Martell, 2004; Rotherham et al., 2007). Numerous sources of bias and uncertainty may arise from the process of obtaining catch-effort data from the wide variety of vessels, capture gears, and landing sites typical of tropical reef fisheries. Also problematic is the non-random strategy of catching fishes employed by fishers with respect to the spatial distributions of species and habitats. Many of these potential biases and uncertainties can be eliminated through the controlled sampling approach offered by fishery-independent (FI) surveys. These surveys can be designed to provide the same size-structured abundance estimates as FD surveys for conducting modern stock assessments (Gunderson, 1993; Ault et al., 1998, 2005b, 2008; Smith and Lundy, 2006). However, FI surveys are usually conducted at much lower levels of sampling effort compared to fishing operations; consequently, FI data have mostly been used as corollary indices to estimate fishing mortality rates and population sustainability benchmarks (Fournier and Archibald, 1982; Deriso et al., 1985; Quinn and Deriso, 1999; Kimura and Somerton, 2006).

Management objectives for coral reefs have now expanded beyond sustainable rates of exploitation for single target species to include the impacts of fishing on ecosystem trophic structure and food-web dynamics (Pauly et al., 1998; Walters and Martell, 2004; Levin et al., 2009), and non-fishing human threats to the productivity of reef-fish stocks from habitat and water quality alterations (Ault et al., 1999b, 2003, 2005a). This ecosystem-oriented perspective has given rise to use of new management tools including no-take marine reserves (NTMRs) that have the dual purpose of controlling exploitation as well as conserving biodiversity in the face of environmental variability (Bohnsack and Ault, 1996). In contrast to FD data sources, FI surveys are well-suited to addressing some of the principal information needs for ecosystem-based management. FI surveys can utilize sampling methods and gears to obtain abundance and size-composition data of both target and

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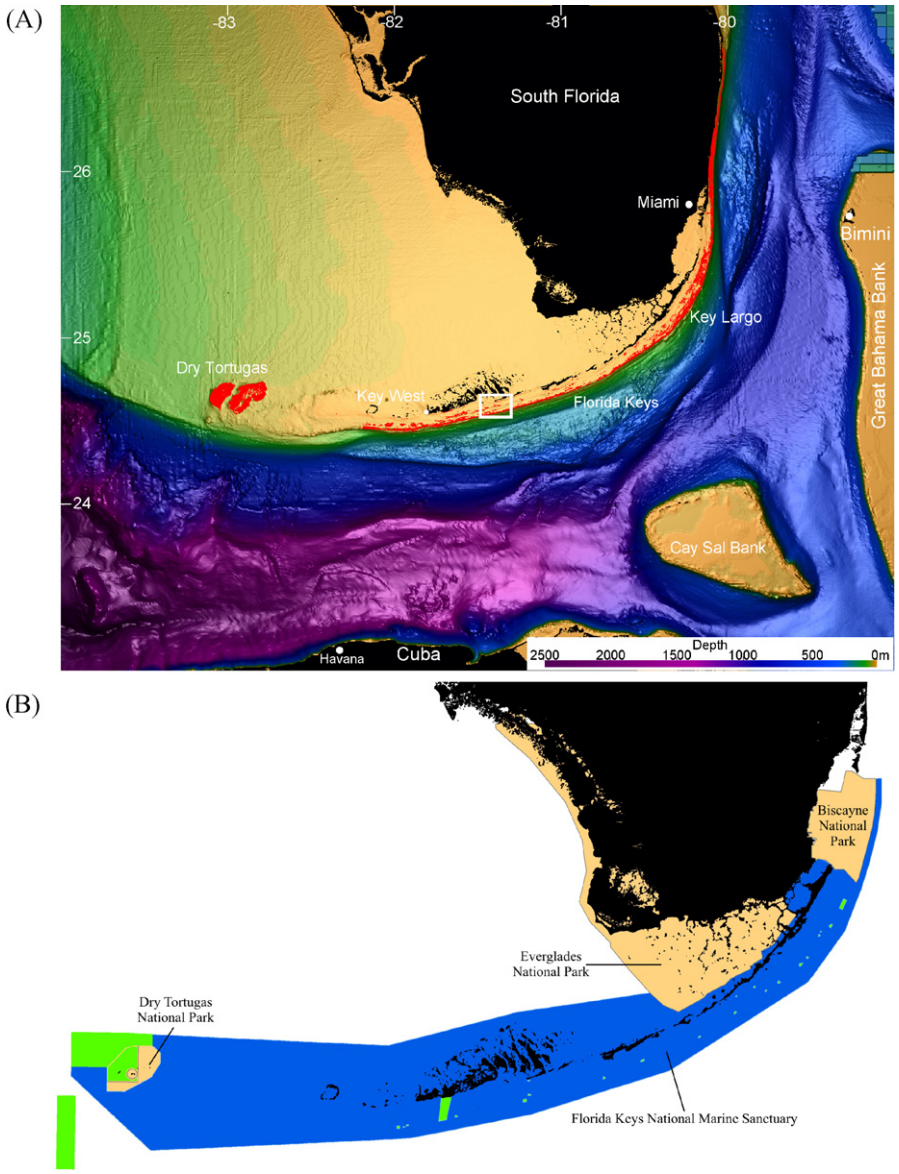

Fig. 1. South Florida reef fish visual survey domain. (A) Seafloor morphology of the coral reef ecosystem and the Straits of Florida with mapped coral reef habitats (red) in the Florida Keys and Dry Tortugas; depths are represented by the color scale; land is black; the rectangle denotes area of detail shown in Fig. 3A. (B) Managed area boundaries for the Florida Keys National Marine Sanctuary (blue), Biscayne, Everglades and Dry Tortugas National Parks (tan), and no-take marine reserves (green).

non-target species, including smaller fishes not subject to capture by a given fishery. FI surveys can also employ sampling designs for evaluating spatially explicit management issues including habitat impacts on stock productivity and the efficacy of NTMRs in reducing exploitation rates (Ault et al., 1999a, 2006).

In this paper we discuss the design and implementation of a fishery-independent, non-destructive, diver visual survey of size-structured population abundance of exploited and non-target fish species in the Florida coral reef ecosystem. We detail how principles of probabilistic sampling design were used to transform a geographically restricted study begun in 1979 to an ecosystem-wide survey in the 1990s that was tailored to provide reliable reef-fish population and community metrics to: (1) support multispecies stock assessments; (2) evaluate the effectiveness of no-take marine reserves (NTMRs) and other spatially explicit management issues; and, (3) estimate metrics of ecosystem condition of the reef fish community. The primary challenge of this research was to design a cost-effective survey that could be conducted annually–biennially over a spatial scale comparable to the commercial and recreational coral reef fisheries in southern Florida, but with enough sampling intensity to provide accurate and precise estimates of population abundance metrics for principal species of the reef-fish community.

2. Material and methods

2.1. Survey sampling approach and spatial domain

A probabilistic sampling approach was used to design a visual survey of reef-fishes that provided population and community metrics for resource management (Cochran, 1977; Thompson, 2002). Visual sampling was conducted along the Florida coral reef tract that extends about 400 km southwest from Miami to the Dry Tortugas (Fig. 1A). The reef tract lies within the management boundaries of the Florida Keys National Marine Sanctuary (FKNMS) and two national parks, Biscayne and Dry Tortugas (Fig. 1B). Our strategy was to use environmental features that correlate with the spatial distribution of reef-fishes to partition the survey area into subareas (i.e., strata) of low, moderate, and high variation in abundance