Short communication

Prey regurgitation in the grouper *Cephalopholis argus*

By J. Dierking* and A. L. Meyer†

*Department of Zoology, University of Hawaii, Honolulu, HI, USA*

Introduction

Groupers (Serranidae: Epinephelinae) are among the most important predatory reef fishes in the tropics and subtropics (Morris et al., 2000). Members of this family commonly regurgitate prey (i.e. expel prey from their stomachs by contraction of the esophageal muscle) during capture both by spearfishing (Kingsford, 1992) and by hook-and-line (Beukers-Stewart and Jones, 2004), presumably as a physiological stress reaction. However, no quantitative estimate of regurgitation has been published to date for a grouper, which poses problems for studies of grouper dietary ecology (Parrish, 1987). In particular, while stomach content analysis of groupers commonly shows high stomach vacuity (i.e. prevalence of empty stomachs), it is usually unclear whether this is a characteristic of feeding ecology, or an artifact of regurgitation (see e.g. Renones et al., 2002). Furthermore, lack to account for regurgitation can strongly negatively bias prey consumption estimates (Bowman, 1986).

Concern about ecosystem level effects of grouper declines due to overfishing (Morris et al., 2000) has led to recent efforts to better describe their feeding ecology. Clearly, lack of data on regurgitation in groupers stands in the way of this effort. The aim of this study was therefore to determine regurgitation rates for the grouper *Cephalopholis argus* in Hawaii obtained by spearfishing, one of the main capture techniques applied in studies of grouper feeding (Parrish, 1987). Specific goals were to interpret the ecological significance of the large stomach vacuity commonly observed in this species, and to use the observed regurgitation rate to develop an approximate correction factor to account for regurgitation in prey consumption estimates of *C. argus*, which may also be applicable to other groupers.

Materials and methods

*Cephalopholis argus* has one of the widest natural distributions of any grouper, ranging from the Red Sea to the central Pacific Ocean. In Hawaii, naturally depauperate of groupers, the species was introduced in 1956 to create a new fishery. In July 2003 a total of 285 *C. argus* specimens from 17 sites in Hawaii were obtained by spearfishing on SCUBA. Following the approach by DeMartini et al. (1996) for the estimate of regurgitation, speared fish were sealed in plastic bags immediately after capture (i.e. underwater). In the few cases in which regurgitation occurred before sealing, regurgitated items were collected from the water column and included in the specimen’s bag. Upon return to the laboratory, each specimen was then analyzed for occurrence of regurgitation (i.e. prey found in the mouth cavity or between the gill rakers, or completely expelled from the mouth cavity and found in the bags). The M of prey items was measured to the nearest milligram, and the degree of digestion classified as ‘Little’, ‘Medium’, or ‘Strong’ based on a scale of external characteristics (not shown). In addition, the standard length (SL) of *C. argus* specimens was determined to the nearest mm, and mass (M) to the nearest 5 g.

Regurgitation rate was calculated as the number of regurgitation incidents per number of specimens that had consumed prey (i.e. specimens with full stomachs and with empty stomachs that were artifacts of regurgitation). In addition, the fraction of the total M of all prey that was regurgitated was calculated. Stomach vacuity (the proportion of individuals with empty stomachs) and mean stomach fullness (M of prey per M of predator) of *C. argus* were then calculated twice: a first time while accounting for regurgitation (i.e. counting empty stomachs that were artifacts of regurgitation as full, and including regurgitated prey M in the calculation), and a second time without accounting for regurgitation. Finally, regurgitation rates for *C. argus* of different SL (<24 cm, 24–30 cm, >30 cm), and containing prey of different digestion status (Little, Medium, Strong), and prey of different M (<2.5 g, 2.5–7.5 g, >7.5 g), were compared using chi-square tests (Minitab version 14).

Results

Overall, regurgitation occurred in 25.7% (41 / 159) of *C. argus* specimens with full stomachs, and led to the loss of 33.2% (473.2 g / 1424.5 g) of the total M of stomach contents. Detailed results of the regurgitation analysis are shown in Table 1. Regurgitation was generally complete (i.e. all stomach contents expelled), which is not surprising as most stomachs contained only a single prey item. The ‘true’ vacuity rate (i.e. accounting for regurgitation) in the analyzed sample was 44.9%, compared to 58.6% when not accounting for regurgitation. This means that almost half of the stomachs in the sample were naturally empty, compared to only 13.7% empty due to regurgitation. Regarding mean stomach fullness, the ‘true’ value was 0.68% of own body M, compared to 0.46% when not accounting for regurgitation. Regurgitation thus...
Table 1
Regurgitation in Cephalopholis argus, as indicated by stomach content analysis of 285 specimens obtained by spearfishing in Hawaii, and by analysis of plastic bags in which specimens were sealed immediately after capture.

<table>
<thead>
<tr>
<th>Stomach status</th>
<th>n</th>
<th>Stomach content mass (in grams)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full, no regurgitation</td>
<td>118</td>
<td>951.3</td>
</tr>
<tr>
<td>Empty, regurgitated prey in plastic bag, gill rakers, or mouth cavity (False empty)</td>
<td>41</td>
<td>473.2</td>
</tr>
<tr>
<td>Empty, no regurgitation (True empty)</td>
<td>126</td>
<td>0</td>
</tr>
<tr>
<td>Regurgitation rate (False empty/)</td>
<td>25.7%</td>
<td>33.2%</td>
</tr>
<tr>
<td>Full and False empty)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

decreased ‘true’ stomach fullness by roughly one-third. Regurgitation rates did not differ significantly between C. argus of different size (chi-square test, d.f. = 2, n = 159, P = 0.50), nor between C. argus containing prey of different digestion status (P = 0.57) or of different size (P = 0.45).

Discussion
Prey regurgitated by groupers during or after capture by spearfishing is likely to be lost if specimens are not sealed underwater, as flushing between capture and removal from the water is extensive. Occurrence of regurgitation in one-fourth of C. argus specimens with full stomachs observed in this study thus clearly indicates that regurgitation needs to be considered when interpreting data from C. argus samples obtained by spearfishing without bagging. In particular, based on the observed reduction in ‘true’ mean stomach fullness [a central component of consumption estimates (Bromley, 1994)] by one-third due to regurgitation, C. argus consumption estimates based on speared and unbagged specimens should be upwardly adjusted by a correction factor of roughly 1.5 to prevent underestimation. In contrast, the insignificant differences in regurgitation rates for C. argus of different sizes, and for prey of different M and digestion status, suggest that analyses of prey composition and comparisons between predator size classes would be little affected by failure to account for regurgitation.

This first report of a regurgitation rate for a grouper allows new insights into grouper feeding ecology. High vacancy rates have been observed for C. argus in other locations (Randall and Brock, 1960), and for grouper species in general (Parrish, 1987), but the authors were not able to address the ecological role of empty stomachs due to the potential confounding influence of regurgitation. Almost half of all stomachs were naturally empty in C. argus in our study, indicating that empty stomachs are an important characteristic of grouper feeding ecology. An explanation may lie in low energy requirements of the generally sedentary groupers compared to active, roving predators such as carangids (Birkeland, 1997).

It should be stressed that regurgitation is not restricted to groupers, but occurs in various marine and freshwater families, e.g. Esocidae (Treasure, 1988), Lutjanidae (DeMartini et al., 1996), and Moronidae (Sutton et al., 2004). Similarly, loss of stomach contents during capture is not limited to spearfishing, but may be even higher for alternative capture methods. For example, hook-and-line caught grouper samples are commonly characterized by larger vacancy rates than spearfished samples (Beukers-Stewart and Jones, 2004), and large regurgitation rates near 50% were found for red hake (Urophycis chuss) caught by trawl fishing (Bowman, 1986) and for pike (Esox lucius) caught in gill nets (Treasurer, 1988). For deep-water species (> 50 m) of all families, a major reason for stomach content loss is stomach eversion caused by swim bladder expansion during rapid decompression (DeMartini et al., 1996), which may be reduced by bringing individuals to the surface more slowly than in commercial fishing (Haight et al., 1993). These examples demonstrate that regurgitation should be considered both in the planning (‘can regurgitation be limited or avoided?’) and the interpretation (‘how does loss of stomach contents influence the data?’) of fish feeding studies, whenever possible.

To conclude, the high regurgitation rate and the loss of a considerable proportion of stomach contents due to regurgitation observed in C. argus indicate that this physiological mechanism must be considered in grouper feeding studies. At the same time, our results suggest that the frequent occurrence of empty stomachs in groupers is a true characteristic of their feeding ecology. Sealing of spearfished specimens underwater was a simple but effective measure to prevent prey loss due to regurgitation. When using this method, considering the scarcity of data on regurgitation (Bowman, 1986), we suggest to always report the observed regurgitation rates, even when this is not the main study objective. In feeding studies of groupers for which regurgitation rates have not been reported, and in which control for regurgitation during collection is not feasible, correction factors based on the values reported for C. argus here can provide a first approximation.

Acknowledgements
We thank T. Clark, S. Fujimoto, W. Walsh, R. Kossaki, and R. Robertson for help with fieldwork. The Hawaii Cooperative Fishery Research Unit and the Hawaii Division of Aquatic Resources provided logistical support. Research was funded by the National Oceanic and Atmospheric Administration, Center for Sponsored Coastal Ocean Science, under award #NA05NOS4261157 to the University of Hawaii for the Hawaii Coral Reef Initiative. The first author was supported by a Fulbright scholarship and the second author by a National Science Foundation fellowship.

References
Bromley, P. J., 1994: The role of gastric evacuation experiments in quantifying the feeding rates of predatory fish. Rev. Fish Biol. Fish. 4, 36–66.

Prey regurgitation in the grouper Cephalopholis argus


**Author's address:** Jan Dierking, Department of Zoology, University of Hawaii, 2538 The Mall, Honolulu, HI 96822, USA. E-mail: jan.dierking@univmed.fr