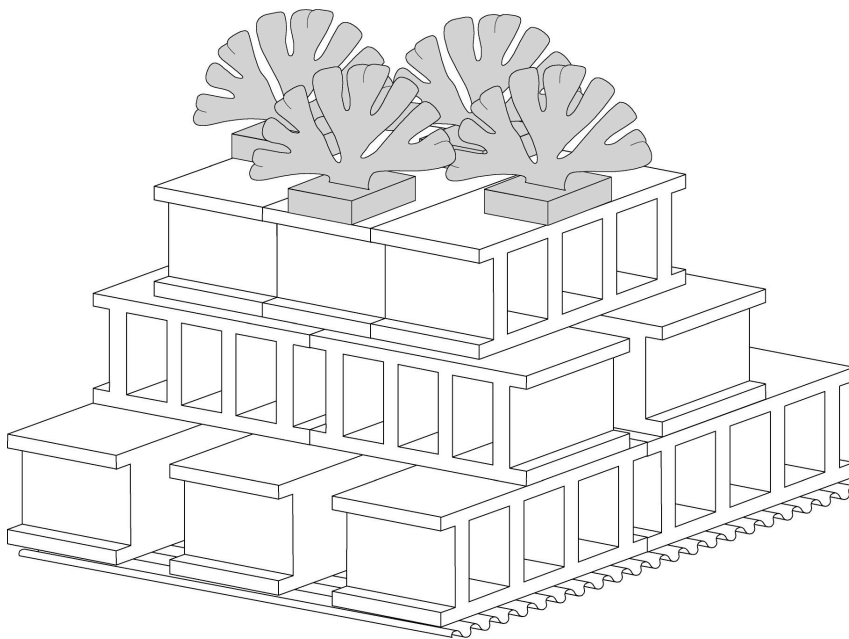


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Predator density and competition modify the
benefits of group formation in a shoaling reef fish.
– Oikos 122: 171–178.

Appendix A1

The construction of experiment 1 reef arrays

Individual reefs were constructed of 13 cinder blocks ($0.5 \times 0.25 \times 0.25$ m), placed on a 1×1 m sheet of corrugated iron. Blocks were stacked with openings facing outward in three tiers forming the shape of a pyramid. Six blocks (3×2) formed the base level, four blocks (2×2) the second tier, and three blocks (3×1) the third tier. On the top of each reef, four *Pocillopora verrucosa* coral heads (mean surface area 0.011 m², SD = 0.004) attached to small cinder blocks (represented here as grey boxes) were placed in a diamond formation on top of reefs to provide shelter for reef fishes.



Appendix A2

Description of predator densities across the natural array

Predator community on experimental patch reefs for experiment 2. The mean (SE) number of individuals for each species is given for each of our wrasse density treatments (3–15 individuals per reef) in the presence (top) and absence of damselfish (bottom). Averages and standard errors are generated from our surveys conducted incrementally on three days during the experiment (30 May, 1 June and 4 June 2007). Total predator densities in bold represent the mean (SE) of the sum of all predators in each treatment per m².

		Wrasse density treatment							
		3	3	3	5	5	8	12	15
Damsel fish present									
Family	Species								
Aulostomidae	<i>Aulostomus chinensis</i>	-	0.3 (0.3)	-	-	-	-	-	-
Balistidae	<i>Balistapus undulatus</i>	0.7 (0.3)	-	-	0.3 (0.5)	-	-	0.3 (0.3)	0.3 (0.3)
Bothidae	<i>Bothus pantherinus</i>	0.3 (0.3)	-	-	0.3 (0.3)	-	-	-	-
Carangidae,	<i>Caranx melampygus</i>	-	-	-	-	-	-	0.3 (0.3)	-
Holocentridae	<i>Neoniphon sammara</i>	-	2.0	-	0.7 (0.7)	0.3 (0.3)	0.7 (0.3)	1.0 (1.0)	3.7 (0.7)
Labridae	<i>Cheilinus trilobatus</i>	-	-	-	-	-	-	0.7 (0.7)	-
Labridae	<i>Halichoeres trimaculatus</i>	1.0 (0.6)	-	2.7 (1.3)	3.3 (0.3)	-	-	0.7 (0.7)	1.0 (1.0)
Muraenidae	<i>Gymnothorax javanicus</i>	-	-	-	-	-	0.7 (0.7)	-	-

Pinguipedidae	<i>Parapercis millepunctata</i>	0.3 (0.3)	-	-	-	1.0 (0.0)	-	-	-
Synodontidae	<i>Saurida gracilis</i>	0.3 (0.3)	-	-	-	0.7 (0.3)	0.3 (0.3)	-	-
	Total	2.7 (0.3)	2.3 (0.3)	2.7 (1.3)	4.7 (0.7)	2.0 (0.6)	1.7 (1.2)	3.0 (0.6)	5.0 (1.5)

Control

Family Species

Aulostomidae	<i>Aulostomus chinensis</i>	-	-	-	0.3 (0.3)	-	0.3 (0.3)	-	-
Balistidae	<i>Balistapus undulatus</i>	-	1.3 (0.3)	-	0.7 (0.3)	-	-	1.0 (0.0)	-
Bothidae	<i>Bothus pantherinus</i>	-	-	-	-	-	-	-	-
Carangidae	<i>Caranx melampygus</i>	-	-	-	-	-	-	-	-
Holocentridae	<i>Neoniphon sammara</i>	-	1.3 (0.3)	0.3 (0.3)	2.0 (0.0)	1.3 (0.3)	1.0 (0.6)	-	1.7 (0.3)
Labridae	<i>Cheilinus trilobatus</i>	-	-	0.7 (0.3)	-	-	-	-	-
Labridae	<i>Halichoeres trimaculatus</i>	1.3 (0.7)	-	1.0 (0.6)	0.7 (0.7)	2.0 (0.0)	-	2.3 (0.7)	0.3 (0.3)
Muraenidae	<i>Gymnothorax javanicus</i>	0.3 (0.3)	-	-	-	-	-	0.3 (0.3)	-
Pinguipedidae	<i>Parapercis millepunctata</i>	-	-	-	-	-	0.7 (0.3)	-	1.3 (0.3)
Synodontidae	<i>Saurida gracilis</i>	-	-	0.3 (0.3)	-	-	-	-	0.7 (0.3)
	Total	1.7 (0.3)	2.7 (0.7)	2.3 (0.7)	3.7 (0.7)	3.3 (0.3)	2.0 (0.6)	3.7 (0.9)	4.0 (0.6)

Appendix A3

Nested hierarchy of models in experiment 1 and 2

Table 1. Parameters for type II functional response modified to incorporate both depletion and baseline mortality. Modified functional response was used to examine whether shifts in attack rate, handling time, predator density affected the mechanisms of inverse density dependence in the wrasse for different predator (experiment 1) and competitor (experiment 2) densities.

Symbol	Description	Units
μ	baseline mortality	1/days
a	per capita attack rate	1/(time \times pred/reef)
h	handling time	Prey/reef/(preda/reef \times days)
P	predator density	pred/reef
T	time	days
N_0	initial no. of prey	prey/reef
N_T	no. of prey at time T	prey/reef
N_e	no. of prey eaten	prey/reef

an estimate of the instantaneous number of prey killed with and baseline mortality can be evaluated using (see text for details):

$$\frac{dN}{dT} = -\left(\mu + \frac{a_i P_i}{1 + a_i h_i N_T}\right) N_T \quad (1)$$

Equation 1 can be integrated to incorporate prey depletion:

$$N_e = -\int_0^T \frac{dN}{dt} dt$$

In experiment 1, we use this integrated model to evaluate differences in attack rate (a) and handling time (h) in the presence of a second predator (hawkfish) (Fig. A1). This same model was used in experiment 2 to evaluate differences in attack rate (a), handling time (h), and effective predator density (P) in the presence of a competitor (damsel) (Fig. A2). Baseline mortality was estimated from Experiment 1 and used to parameterize experiment 2.

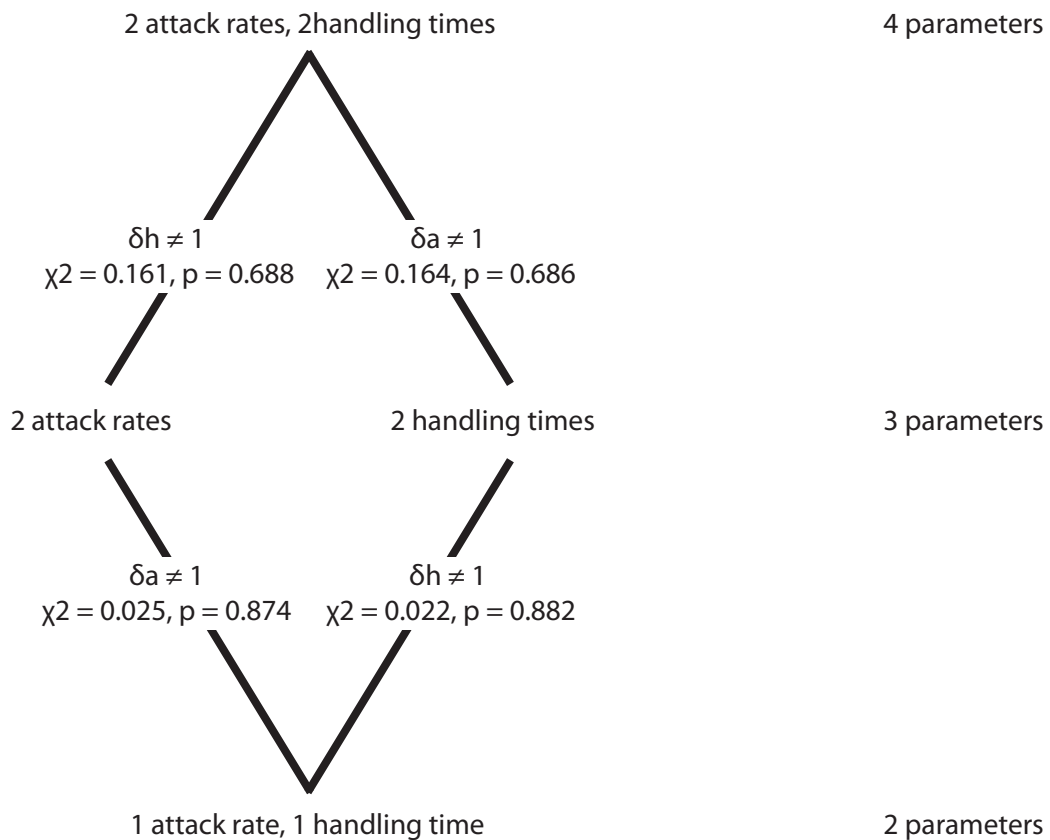


Figure A1. Nested models in experiment 1 examining the effect of a doubling in hawkfish density on attack rate and handling time of hawkfish. χ^2 -values are equal to the difference in the deviance between the two Rogers random predator (RRP) models. Significant p-values (bold) represent a statistically significant likelihood ratio test (LRT). Significance in the LRT suggests the more complex of the two models is a better fit.

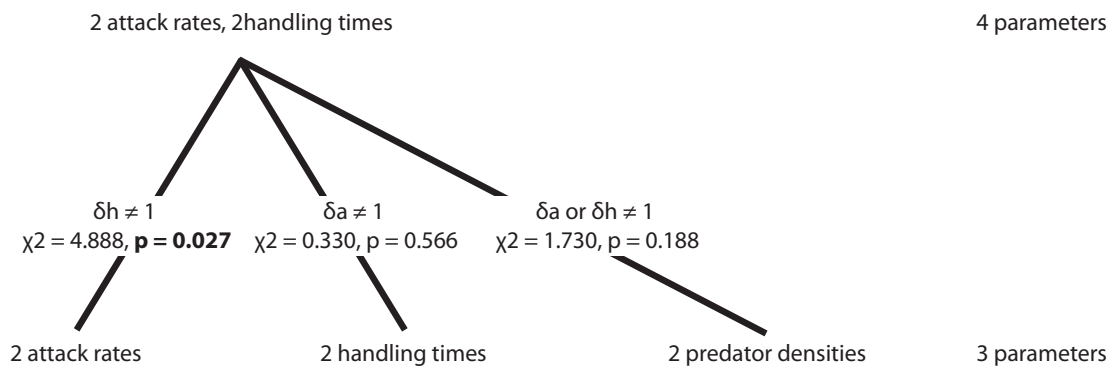


Figure A2. Nested models in experiment 2 examining the effect of damselfish addition on attack rate, handling time, and effective predator density. Comparisons among candidate models suggest two appropriate models: 1) the model with different handling times 2) the model with different effective predator densities. See Fig. A1 legend for more details.

Appendix A4

Functional responses with predator density

Functional response models allowing attack rate (a) and handling time (h) to vary with each of the experimental treatments for one and two predators. Our models (far right) are specific versions of existing functional response models (far left) that explore the role of predator density in affecting predator foraging behavior. Moving from left to right shows how the original formulation of these models, can be simplified to be identical to our model under scenarios where there are 1 and 2 predators. Our models are not equivalent to existing models for $P > 2$. See Skalski and Gilliam (2001) for more details.

Model	Original formulation	1 Predator $f_i(N, P_1)$	2 Predator $f_i(N, P_2)$	2 Predator (simplification)	Our model
Holling type II	$f_{H2}(N, P) = \frac{aNP}{1 + bN}$	$\frac{aN}{1 + bN}$	$\frac{2aN}{1 + bN}$	$\frac{2aN}{1 + bN}$	$\frac{aNP}{1 + ahN}$
Beddington-DeAngelis	$f_{BD}(N, P) = \frac{aN}{1 + bN + c(P - 1)}$	$\frac{aN}{1 + bN}$	$\frac{aN}{1 + bN + c}$	$\frac{aN / 1 + c}{1 + bn / (1 + c)}$	$\frac{(a_1 \cdot \delta a)NP}{1 + (a_1 \cdot \delta a)hN}$
Crowley-Martin	$f_{CM}(N, P) = \frac{aN}{1 + bN + c(P - 1) + bcN(I)}$	$\frac{aN}{1 + bN}$	$\frac{aN}{1 + bN + c + bc\Lambda}$	$\frac{a}{1 + c} \frac{N}{1 + Nb}$	$\frac{aN(P_1 \cdot \delta P)}{1 + aNh}$
Hassell-Varley	$f_{HV}(N, P) = \frac{aN}{bN + P^m}$	$\frac{aN}{1 + bN}$	$\frac{aN}{bN + P^m}$	$\frac{aN}{\frac{2^m}{2^m} + 1}$	$\frac{aN(P_1 \cdot \delta P)}{1 + aNh}$