Biological Sciences, Ecology

Title: Climate drives the geography of marine consumption by changing predator communities

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86 **Abstract:** The global distribution of primary production and consumption by humans (fisheries)
87 are well-documented, but we have no map linking the central ecological process of consumption
88 within food webs to temperature and other ecological drivers. Using standardized assays that
89 span 105 degrees of latitude on four continents, we show that rates of bait consumption by
90 generalist predators in shallow marine ecosystems are tightly linked to both temperature and the
91 composition of consumer assemblages. Unexpectedly, rates of consumption peaked at mid-
92 latitudes (25-35°) in both northern and southern hemispheres across both seagrass and
93 unvegetated sediment habitats. This pattern contrasts with terrestrial systems, where biotic
94 interactions reportedly weaken away from the equator, but it parallels an emerging pattern of a
95 subtropical peak in marine biodiversity. The higher consumption at mid-latitudes was closely
96 related to the type of consumers present, which explained rates of consumption better than
97 consumer density, biomass, species diversity, or habitat. Indeed, the apparent effect of
98 temperature on consumption was mostly driven by temperature-associated turnover in consumer
99 community composition. Our findings reinforce the key influence of climate warming on altered
100 species composition and highlight its implications for the functioning of Earth's ecosystems.
101
102 **Keywords:** latitudinal diversity gradient, macroecology, biogeography, trophic processes,
103 climate, seagrass
104
105 **Significance Statement (max 120 words):**
106 Consumption transfers energy and materials through food chains and fundamentally influences
107 ecosystem productivity. Therefore, mapping the distribution of consumer feeding intensity is key
108 to understanding how environmental changes influences biodiversity, with consequent effects on
109 trophic transfer and top-down impacts through food webs. Our global comparison of
110 standardized bait consumption in shallow coastal habitats finds a previously unrecognized peak
111 in feeding intensity away from the equator that is better explained by the presence of particular
112 consumer families than by latitude or temperature. This study complements recent
113 demonstrations that changes in biodiversity can have similar or larger impacts on ecological
114 processes than those of climate.
115

3

Text

Latitudinal diversity gradients have stimulated decades of research, much of it invoking a decline from tropics to poles in rates of key biological processes and species interactions (1–3). General explanations for ecological patterns across latitude, however, remain elusive in part because so many environmental and biological variables change in parallel with latitude. As a result, the connections between ecological patterns and processes at global scales remain controversial (4–6). This uncertainty has recently been amplified by demonstrations that diversity of many modern and ancient lineages peaks at mid-latitudes rather than at the equator, particularly in the ocean (7, 8).

Temperature is among the environmental factors that vary most consistently with latitude, and is a fundamental driver of biological processes. Metabolic theory mechanistically links environmental temperatures to a suite of biological processes, including metabolism and trophic transfer (9–12). For example, metabolic theory predicts that per capita consumption rates of ectothermic consumers should follow increased metabolic needs and activity, and increase with rising temperature (13). But the traits of consumers, their abundance, and the resources available to them also change with temperature (14, 15), so total consumption rates may be poorly predicted by temperature alone. Separating these effects requires data on geographic variation in consumption.

Our understanding of global variation in top-down processes in marine systems is largely indirect, based on inferences from distributions of organismal traits such as body size and morphological defenses (e.g., 2, 16) and on comparisons of primary production, prey abundance, and predator abundance (e.g., 17, 18). The distribution and abundance of species respond to ecosystem productivity, reproductive rate, migration, mortality, and evolutionary history, all of which are modified by temperature (e.g., 19, 20). But while the spatial distribution of primary production and human predation (fishing) are well-documented (21, 22), we have only sparse empirical measurements of geographic variation in consumption by natural predators, which is needed to predict trophic transfer and prey abundance. Thus, we lack a global map linking the central ecological process of consumption to temperature and other drivers.

We approached this problem by measuring feeding intensity of generalist marine consumers across 42 sites around the globe representing two widespread coastal habitats: seagrass and unvegetated sediments. These critical habitats provide shelter and fuel primary and secondary production (23–25), and seagrass persistence is in turn linked to trophic processes, as mid-level carnivores consume herbivores that can facilitate or damage seagrass (26–30). Therefore, understanding consumption by mid-level predators is key to seagrass conservation and restoration efforts (30).

155   To compare consumption rigorously around the world's coasts, we used a simple, standardized
156   feeding assay, offering small (~1 cm) discs of dried squid mantle as bait. Squid is attractive to
157   many generalist marine predators, including mid-sized fishes and crustaceans, which we
158   surveyed in both seagrass and unvegetated habitats. Importantly, standardizing bait allowed us to
159   estimate consumption rates on a comparable basis while avoiding confounding influences of
160   geographic variation in prey type, prey behavior, and prey defenses. Previous studies (e.g., 31,
161   32) have shown changes in feeding on standardized prey across latitude, but ours covers nearly
162   the entire latitudinal range of seagrasses on four continents, and multiple ocean basins in both
163   northern and southern hemispheres (our study, 38°S-67°N; seagrass, 45°S-70°N). This allowed
164   us to test the consistency of latitudinal gradients in consumption in two widespread habitats, and
165   to begin disentangling the role of correlated drivers. Based on previous studies documenting
166   broad-scale patterns in biodiversity (3, 33, 34), prey defense (2), trophic interactions (5, 35, 36),
167   and metabolism (12), we hypothesized that rates of bait consumption would increase with
168   temperature toward the equator.
169
170   **Results and Discussion**
171   Contrary to our expectations, bait consumption peaked away from the equator in both
172   hemispheres (25-35° North and South), and was consistent between seagrass and sediment
173   habitats (Fig. 1A), despite slightly higher density, richness, and biomass of consumers in
174   seagrass (SI Appendix, Fig. S1). Although our sampling near the equator was relatively sparse,
175   the decline in measured bait consumption at the lowest latitudes was robust in two independent
176   regions (SI Appendix, Fig. S2). This mid-latitude peak was supported by a hump-shaped
177   relationship between absolute latitude and consumption (comparison of models with and without
178   second-order polynomial; quadratic model Akaike weight $w_{quad} = 0.86$). In contrast, satellite-
179   derived mean annual sea surface temperature decreased monotonically with latitude (SST; Fig.
180   1C), and the hump-shaped relation of SST to consumption was much stronger than that for
181   latitude ($w_{quad} > 0.99$). This nonlinear relationship between SST and consumption was also
182   supported in two independent, well-sampled transects along the Northwest Atlantic ($w_{quad} =$
183   0.97) and Southwest Pacific ($w_{quad} = 0.99$; SI Appendix, Fig. S2), strengthening the inference
184   that the equatorial dip in consumption reflects a response to temperature, rather than some other
185   correlate of latitude.
186
187   Fish and crabs were the main consumers of bait at all sites, and their taxonomic composition
188   varied greatly across sites and with temperature (Fig. 2). Because species and genera of coastal
189   animals differ markedly across ocean basins and hemispheres, we analyzed consumer
190   composition at the level of taxonomic families, which allowed us to describe gradual shifts in
191   global consumer biogeography across broad environmental gradients, while maintaining
192   functional distinction among taxa. We used presence vs. absence rather than abundance data
193   because we wanted to explore consumer composition and abundance separately. Mean annual
194   sea surface temperature alone explained 16% of the dissimilarity in fish and crustacean

195   assemblages across sites (canonical analysis coefficient = 0.13, P = 0.001). However, a single
196   unconstrained index of compositional dissimilarity (Principal Components Axis 1 in Fig. 2A)
197   explained 19.5% of the total variation in consumer composition, and separated cool-water
198   assemblages from warm assemblages (37). Indeed, this index of consumer composition was a
199   stronger predictor of bait consumption than water temperature (either measured during the assays
200   or using mean annual sea surface temperatures; SI Appendix, Fig. S3), latitude, consumer
201   density and biomass, or estimates of ocean productivity, fishing pressure, or human population
202   density (Table 1). Consumer density and biomass only became important predictors of
203   consumption once we reduced the dataset to include only those consumer families whose
204   presence was associated with increased consumption rates (see Methods, SI Appendix, Table
205   S1). When viewed as a simple network of causal relationships, the effect of thermal environment
206   on consumption rate was largely indirect, being mediated by consumer community composition,
207   and this remained true even when allowing for a nonlinear relationship between consumption
208   rate and mean annual sea surface temperature (Fig. 3). Roughly three-quarters of the total effect
209   of thermal environment on bait consumption flowed indirectly through differences in consumer
210   taxa in different climates.
211
212   Locations with high consumption rates had consumer assemblages composed largely of
213   invertivores and omnivores that actively forage on or just above the seafloor (SI Appendix, Fig.
214   S3-4). Actively swimming foragers should consume bait faster due to increased encounter rates,
215   all else being equal, and arguably consumption by these foragers might rise more rapidly with
216   temperature than for more sedentary taxa. Video evidence confirmed the association of key
217   families with high consumption. Porgies (family Sparidae), for example, removed bait at every
218   site where they were observed in video footage (SI Appendix, Table S2) and the presence of this
219   family showed the strongest association with consumption rate in our analysis of community
220   composition (Fig. 2B, SI Appendix, Table S1).
221
222   The equatorial decline in bait consumption appears to be related to consumer community
223   composition, as many of the actively foraging taxa associated with high consumption rates,
224   including porgies, half-beaks (Hemiramphidae), and grunts (Haemulidae), were rare or absent at
225   the sites closest to the equator (SI Appendix, Fig. S5). Some of these consumer families (e.g.,
226   porgies) are known from low latitude waters but were not recorded in our surveys (38). It is
227   possible that larger enemies reduce mesopredator abundance or restrict their foraging (39, 40) to
228   a greater extent at low latitudes, but we do not have any direct evidence to support this
229   hypothesis. Similarly, human harvest or other activities could have restricted the abundance of
230   these key consumers, but we know of no reason to expect this to be more intense at low latitudes,
231   as many of the middle and high latitude sites in this study are heavily influenced human
232   activities, including overfishing (41). Alternatively, environmental tolerances could limit
233   consumer access or abundance in shallow seagrass habitats at low latitude (42). There is
234   currently little evidence to evaluate these explanations.

235

236   Our finding that feeding intensity peaked at mid-latitudes differs strongly from most previous
237   studies on latitudinal gradients in species interactions (5, 12, 31, 36). Non-linear ecological
238   transitions between warm-temperate and subtropical locations might help explain this result.
239   These regions feature rapid transition between thermal guilds of consumers with cool- vs. warm-
240   water affinities (37) and these biogeographic transitions are correlated with shifts in the relative
241   strength of bottom-up vs. top-down processes that are directly and indirectly related to
242   temperature (17). We find it interesting that such transitions co-occur in similar climatic regions:
243   transitions in consumption from this study (~19-22°C SST), transitions in dominant fish guilds
244   (~21-25°C SST; 37), and transitions in top-down vs. bottom-up control (~17-20°C temperature
245   0-200m; 17). These comparisons suggest that zones of biogeographic and trophic transitions
246   associated with climate are also areas of transition for consumptive pressure by small
247   mesopredators.

248

249   The weak and inconsistent differences we found in consumption rates between seagrass vs.
250   unvegetated sediment habitats (SI Appendix, Fig. S6-7) was surprising given decades of research
251   showing that the structure provided by seagrasses and other foundation species can strongly
252   influence predator-prey relationships (43–46). While we found no overall difference in consumer
253   composition between seagrass and unvegetated habitats (permutation test, P = 0.75), consumer
254   densities were generally higher inside than outside of seagrass habitat (SI Appendix, Fig. S1).
255   Thus, any protection provided by seagrass structure may have been offset by consumer
256   aggregation in seagrass. Yet the consistency of latitudinal patterns in consumption between the
257   two habitats suggests that broad-scale environment and consumer biogeography had stronger
258   influences on consumption than local differences in habitat structure.

259

260   Our feeding assay used identical bait at all sites to isolate the effect of consumer activity from
261   the behavioral and morphological traits of prey, which vary widely across space. No single bait
262   will attract all predators equally; ours targeted the small to medium-sized generalists that
263   dominate many shallow marine habitats. Thus, the consumption rates that we describe are
264   relative measures of one-half of a predator-prey interaction (i.e., consumption in the absence of
265   prey behavior and other trait variation). Whereas this design cannot completely characterize
266   species interactions, standardization more rigorously estimates how potential consumption varies
267   across the globe. Our assays did not measure top-down control per se, but the kind of
268   information we gathered is critical to understanding trophic interactions, including cascading
269   effects in seagrass ecosystems (30, 47, 48), because it measures the willingness of consumers to
270   eat prey of a certain size. The consistency of our results across ocean basins and hemispheres,
271   along with similar recent findings for pelagic top predators (49), suggests that the mid-latitude
272   peak in marine consumption is indeed general. The importance of particular predator taxa and
273   traits in the geography of consumption we found parallels the outsized role of endothermy in the
274   effectiveness of marine predators (e.g., 50, 51), including in some seagrass meadows (47, 48).

275   We focused on the smaller ectothermic consumers that consume herbivorous invertebrates that
276   can be critical to seagrass persistence (32), but these are potential prey of larger endotherms like
277   fishing birds and small marine mammals, so endothermy might well influence the broader food
278   webs we studied. However, given that many endothermic predators are most abundant and
279   diverse in cooler regions of the world ocean (51), we would expect the distribution of their
280   collective feeding intensity to differ from the pattern we observed.
281
282   Changing climate, overfishing, and global species introductions are altering the biogeography of
283   marine life and the composition of communities (52, 53), with wide-ranging effects on
284   ecosystems (54), including in seagrass habitats (55). Shifting biogeography of consumers can
285   alter community and ecosystem structure and processes (56, 57) independent of temperature, as
286   we show here. Simultaneously, warming can directly influence physiology of ectothermic
287   consumers (e.g., metabolic demand, activity; 58). We show that variation in water temperature
288   influences marine trophic process mainly indirectly by changing consumer community
289   composition. The hump-shaped relationship between temperature and consumption we found
290   suggests that predation and trophic transfer may intensify at middle to high latitudes and decline
291   near the equator as the world ocean warms and species continue to shift their ranges. Such shifts
292   in species ranges and biomass distributions could lead to large changes in consumption, with
293   repercussions for community structure and trophic flows through marine food webs. It is already
294   clear that many ectotherms are expanding or contracting their ranges with climate change (59,
295   60). Our findings suggest that such distributional shifts may affect ecological processes as much
296   or more than those predicted based only on temperature effects on metabolism.
297

298   **Materials and Methods**
299   We assessed rates of consumption using a simple, standardized field assay (61). We tethered a 1-
300   1.3 cm diameter piece of dried squid mantle with monofilament to a fiberglass garden stake
301   (hereafter, 'squidpop'), that we inseted into the sediment such that the bait dangled 20-30 cm
302   above the sediment surface in or just above the seagrass canopy. At most sites, we deployed 20-
303   30 squidpops within a seagrass meadow and 20-30 squidpops in nearby unvegetated sediments
304   (SI Appendix, Table S3). We checked the squidpops for presence (1) or absence (0) of bait after
305   one hour and again after 24 hours. Most sites repeated this assay for a total of three deployments
306   in each of the two habitat types, and measured water temperature during each deployment.
307
308   To characterize variation in environments across the range of the study, we drew upon several
309   publicly-available datasets with global-scale variables of interest. We accessed sea surface
310   temperature and chlorophyll records using Bio-ORACLE (62), which packages data collected by
311   the Aqua-MODIS satellite. We used mean annual sea surface temperature (SST) because it
312   showed stronger relationships with consumption rate than maximum or minimum annual SST
313   and it summarizes well the differences between thermal conditions across the globe (Fig. 1).
314   Most assays were conducted during the summer, but differences in timing of assays generated

315   variation in *in situ* temperature that altered the rank-order of our estimates of the thermal
316   environments compared to sea surface temperature, making nearby sites appear less similar
317   environmentally (Fig. 3). We used mean annual chlorophyll *a* as a proxy for surface ocean
318   primary productivity across sites. We also accessed data on human population densities from the
319   Gridded Population of the World (63), which we used as a proxy for local human disturbance.
320   Finally, we accessed fishing pressure data from the Sea Around Us project (64) using the R
321   package 'seaaroundus' (65).
322
323   At most sites (30 of 42 sites) we also conducted consumer surveys in the areas adjacent to
324   feeding assays. These surveys used hand-pulled seines in seagrass and unvegetated sediment
325   habitats to sample epibenthic consumers (mainly fishes, but also large crustaceans) adjacent to
326   feeding assays. All consumers were identified, counted, and released. The total lengths of the
327   first 25 individual fish of each species were also measured. We used these data to estimate
328   consumer density, size distribution, biomass, and diversity, as well as to generate a species list
329   for each site. Species lists from five additional sites were added using data from video footage
330   and diver transects (FL, India, Italy, Yuca1, Yuca2; SI Appendix Movie S1). Biomass estimates
331   were calculated using length-weight regressions available in Fishbase (66).
332
333   For each of the squidpop assays we independently fitted an exponential decay model and
334   estimated consumption rate (bait loss through time) using the slope parameter. We then used the
335   resulting rate estimates as data points in subsequent analysis.
336
337   We predicted individual consumption rates in generalized linear mixed effects models (logit link,
338   random intercepts for sites) using a variety of potential abiotic and biotic drivers, and compared
339   models using Akaike Information Criterion corrected for small sample size calculated using the
340   R package 'bbmle' (67). We also explored a variety of polynomial terms and LOESS curves to
341   investigate possibilities of non-linear relationships between temperature and consumption,
342   although for model comparison we only included linear terms. We restricted the data used in
343   model comparison to the 27 sites for which we had the full complement of explanatory variables.
344   For simplicity, and because our analysis was largely exploratory using a large set of candidate
345   explanatory variables, we compared models with individual predictor variables only. All mixed
346   models were fitted using maximum likelihood in the package 'lme4' in R (68).
347
348   When estimating consumer species (alpha) diversity, we used both species richness and
349   Hurlbert's probability of interspecific encounter as effective numbers of species (69). We also
350   wanted to investigate changes in consumer community composition across sites (beta diversity),
351   but given the scale of our analysis and the large biogeographic gradients we captured, comparing
352   composition in terms of species identity was not possible. Species level overlap was low among
353   sites, especially across ocean basins and hemispheres, so we chose to compare composition
354   (presence-absence) at the level of families across sites using Raup-Crick dissimilarities. While

355   this metric has been used to investigate small spatial scale differences in species composition
356   within regions (70), we use it here to investigate global among-site turnover of consumers at
357   higher taxonomic levels. In order to visualize and quantify major axes of community variation,
358   we used Principal Coordinates Analysis (PCoA) to ordinate consumer communities based on
359   their dissimilarities, and then assess how these dissimilarities related to the thermal environment
360   and consumption rate. We used a combination of unconstrained (PCoA) and constrained
361   (Canonical Analysis of Principal Coordinates) techniques in this analysis. Unconstrained
362   ordination reduces dimensionality of the dataset by finding orthogonal axes of decreasing
363   variation in the dataset, while constrained ordination uses a regression-based approach to define
364   a set of axes of interest a priori based on explanatory variables (71). We used the resultant axes
365   from unconstrained ordination (PCoA) as explanatory variables in the models described above
366   because the unconstrained ordination does not require a priori assumptions about which factors
367   are important. We also assessed relationships between consumer community composition and
368   thermal environment by constraining the first ordination axis to SST or *in situ* temperature.
369   Multivariate analyses were performed using the R package 'vegan' (72).
370
371   In order to identify which consumer families were positively and negatively associated with
372   consumption intensity across sites, we constrained the first axis of the ordination to align with
373   our estimates of consumption rate. Then we selected families that mapped onto the positive side
374   of this axis as candidate taxa driving spatial variation in consumption rate, and calculated the
375   density and biomass of these consumers at sites with seining data (27 of 42 sites). Finally, we
376   compared the results from multivariate analysis to direct observations of squidpop attacks and
377   bait removal from video footage captured at 14 sites (SI Appendix Table S2).
378
379   To explore which predator traits might explain feeding intensity in our assays, we scored six
380   traits for each taxon in our dataset (416 morphospecies in 103 taxonomic families). Four traits
381   were derived from Fishbase (feeding habit, lateral body shape; 73) and Reef Life Survey (trophic
382   group, water column usage; 74). A fifth binomial trait scored whether each taxon is an actively
383   swimming forager or tends towards ambush or sit-and-wait behavior, either on the benthos or in
384   the water column. We applied the most common value of this trait to all taxa in each family, but
385   we acknowledge that variation in foraging activity can occur within families. Traits missing in
386   these databases were filled using expert opinion of co-authors and available trait information
387   from related taxa. A sixth continuous trait describing body size as the average total length of
388   each taxon (carapace width for crabs) was calculated from our seining data. Whereas published
389   total length estimates are available for many taxa, we opted to use length estimates from our own
390   dataset because many taxa only utilize seagrass and other nearshore habitats for part of their
391   development, when they may differ greatly from the species' maximum size. Using the R
392   package 'FD' (75) we calculated community-level weighted means of trait values to derive
393   estimates of average conditions for each of the six individual traits in each site and habitat
394   combination in the dataset, and we calculated a variety of functional diversity metrics (functional

395 richness, functional dispersion, functional evenness, functional diversity, and Rao's Q) following
396 published methods (75–77). For all consumer functional diversity metrics and all community-
397 level weighted means except body size we used presence-absence data instead of weighting by
398 relative abundance so that we could include sites with seining and video data. We did weight
399 mean consumer body size estimates by relative abundance because we only had size estimates
400 from seine sampling. Weighting by abundance did not qualitatively change the results. We
401 regressed each functional diversity metric and each community-level weighted mean trait against
402 consumption rate individually using the linear mixed effects models described above.
403
404 We tested whether consumer composition mediated the influence of mean annual SST on
405 consumption rates using the package 'mediation' in R (78). Because we found support for a
406 hump-shaped relationship between SST and consumption rate, we tested whether consumer
407 composition mediated the non-linear relationship between temperature and consumption rate
408 (using 33 of 42 sites with all three variables). We modeled the relationships using 1) smooth
409 terms for SST on consumption rate and a linear term for composition (PCoA1) on consumption
410 rate in a generalized additive model (GAM; logit link function; R package 'mgcv' 79) and 2) a
411 general linear model for SST on composition. We report the standardized linear regression
412 coefficients, estimated degrees of freedom for smoothed GAM terms (and associated chi-square
413 statistic), estimates of the mediation effect and direct effect, and the proportion of the direct
414 effect of SST mediated by composition for the second mediation analysis, along with 95%
415 confidence intervals around estimates of the direct effect, mediation effect, and the proportion
416 mediated. All models in mediation analysis used data that were averaged at the level of habitats
417 within sites, which is the lowest level of pairwise comparisons we can make between squidpop
418 assays and consumer composition.
419
420 All analyses were performed in R version 3.5.3 (80). Data and analyses for this project are
421 available at https://doi.org/10.5281/zenodo.3998836.
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597

16

Figures

Figure 1. Distributions of bait consumption by generalist marine predators and temperature across the 42 sites in this study. A) Consumption rate of tethered dried squid bait peaks at mid-latitudes in both hemispheres. Point color represents habitat, and lines show independent quadratic GLMs fitted for each habitat type in each hemisphere. B) Map of study sites. C) Latitudinal pattern of mean annual sea surface temperature (SST).

Figure 2. The composition of consumer assemblages reflects global gradients in environmental temperatures and consumption rate. A) Principal coordinates analysis, where locations of symbols reflect compositional differences among sites and habitats based on family-level presence-absence data. Symbol color represents mean annual sea surface temperature (°C), and symbol size corresponds to bait consumption rate. B) The same ordination showing scores for consumer families driving differences in composition and consumption rate among sites. Symbol color represents average in situ temperature at sites where the predator family was observed label color represents positive (red), negative (purple), or non-significant (black) correlations with consumption rate, and body length (width for crabs) is proportional to the magnitude of the correlation. Asterisks denote families that were seen feeding on bait in video footage.
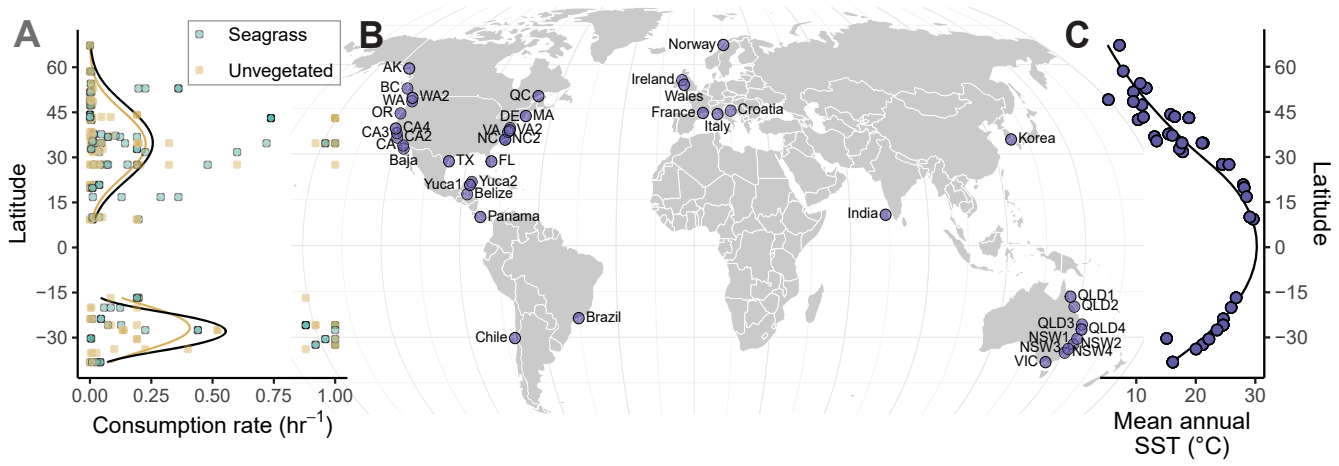
Figure 3. Predator composition mediates the effect of thermal environment on consumption rates. (A-C) Bivariate relationships between consumer composition (PCoA1, Fig. 2A), thermal environment (SST) and consumption rate. Lines show predictions from models used in mediation analysis (A, linear regression; B, logistic regression; C, generalized additive modeling). D) Paths represent causal hypotheses about relationships. Numbers next to paths leading to and from consumer composition are standardized regression coefficients and standard errors. Numbers above and below the path from thermal environment to consumption rate are estimated degrees of freedom and chi-square values for the smooth term in the presence and absence of mediation, respectively. Numbers above the path diagram are estimates of the direct and indirect (mediation) effects with 95% bootstrapped confidence intervals.
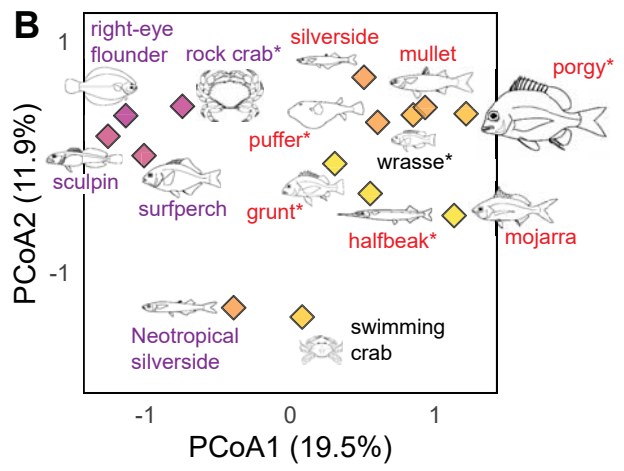
642   **Tables**

643

644   Table 1. Comparison of generalized linear mixed effects models predicting bait consumption by

645   generalist consumers in two shallow marine habitats

A

Seagrass
Unvegetated

Latitude

Consumption rate (hr^{-1})

B

AK
BC
WA
OR
CA3 CA4
CA1 CA2
Baja
WA2
QC
DE MA
VA1 VA2
NC NC2
TX FL
Yuca1 Yuca2
Belize
Panama
Brazil
Chile
Norway
Ireland
Wales
France
Italy
Croatia
Korea
India
QLD1
QLD2
QLD3 QLD4
NSW1 NSW2
NSW3 NSW4
VIC

C

Latitude

Mean annual
SST (°C)

A

PCoA2 (11.9%)

PCoA1 (19.5%)

rate
- 0.00
- 0.25
- 0.50
- 0.75

SST
30
25
20
15
10
5

B

PCoA2 (11.9%)

PCoA1 (19.5%)

right-eye flounder
rock crab*
silverside
mullet
porgy*
puffer*
wrasse*
sculpin
surfperch
grunt*
halfbeak*
mojarra
Neotropical silverside
swimming crab

A

PCoA1 vs SST

B

Consumption rate vs PCoA1

C

Consumption rate vs SST

D

Mediation Effect (AB)	0.24	(*0.14,0.34*)
Direct Effect (C)	0.09	(*-0.06,0.22*)
Proportion Mediated	0.73	(*0.46,1.46*)

Consumer
Composition

(A)
8.4 ± 0.3

(B)
2.0 ± 0.5

Thermal
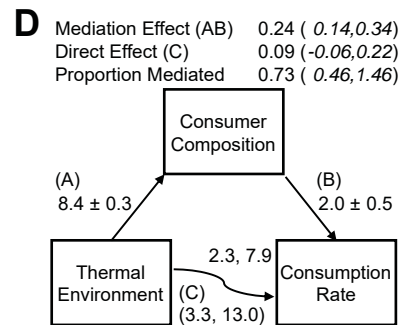Environment

2.3, 7.9

(C)
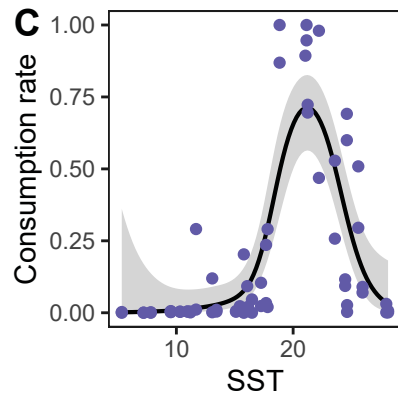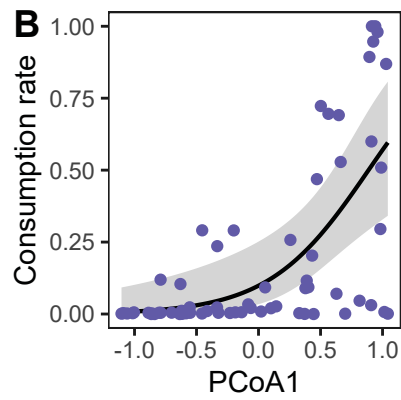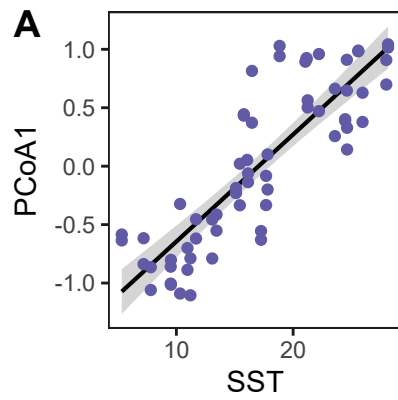(3.3, 13.0)

Consumption
Rate

Table 1. Comparison of generalized linear mixed effects models predicting bait consumption by generalist consumers in two shallow marine habitats

Candidate models	k	AICc	ΔAICc	w_i	R^2
Taxonomic Composition	3	70.3	0	0.932	0.51
Selected Abundance	3	77.0	6.7	0.033	0.39
(Sea Surface Temperature)^2	4	79.2	8.9	0.011	0.66
Selected Biomass	3	79.6	9.3	0.009	0.38
Functional Richness	3	79.9	9.5	0.008	0.26
Sea Surface Temperature	3	80.5	10.2	0.006	0.39
in situ Temperature	3	82.8	12.5	0.002	0.31
Productivity	3	90.5	20.2	<0.001	0.12
Proportion of Active Foragers	3	90.5	20.2	<0.001	0.10
Body size	3	90.6	20.3	<0.001	0.10
Consumer Species Richness	3	90.8	20.5	<0.001	0.05
Functional Evenness	3	91.4	21.1	<0.001	0.04
Intercept-Only	2	92.0	21.7	<0.001	0
Trophic Group	6	92.1	21.8	<0.001	0.27
Functional Group Richness	3	92.2	21.9	<0.001	0.04
Feeding Type	3	92.4	22.1	<0.001	0.15
Habitat	3	93.1	22.8	<0.001	0.01
Lateral Body Shape	6	93.1	22.8	<0.001	0.23
Total Biomass	3	93.2	22.9	<0.001	0.02
Effective Number of Species	3	93.2	22.9	<0.001	0.01
Total Abundance	3	93.3	23.0	<0.001	0.02
Fishing Pressure	3	93.6	23.3	<0.001	0.02
Water Column Use	6	93.7	23.4	<0.001	0.20
Human Population Density	3	94.0	23.7	<0.001	<0.01
Rao Q	3	94.0	23.7	<0.001	<0.01
Functional Dispersion	3	94.0	23.7	<0.001	<0.01

Taxonomic Composition refers to the first axis from the PCoA of consumer assemblages (Fig. 2). Selected Abundance and Biomass refer to density or biomass of fish and decapod families selected through constrained ordination (Fig. 2B, SI Appendix, Table S1). Productivity refers to remotely-sensed mean annual chlorophyll *a*. Habitat categorically relates seagrass and unvegetated habitats. Abundance, biomass, and human population density were $\log_{10}$-transformed. Body size, Trophic Group, Lateral Body Shape, and Water Column Use are community-weighted mean trait values by site and habitat. We provide marginal pseudo-R^2 values for comparison of fixed effects. For model comparison we only included data from sites with the full complement of predictors (27 of 42 sites).