Ecography

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Supplementary material

Appendix 1. Stable isotope data.

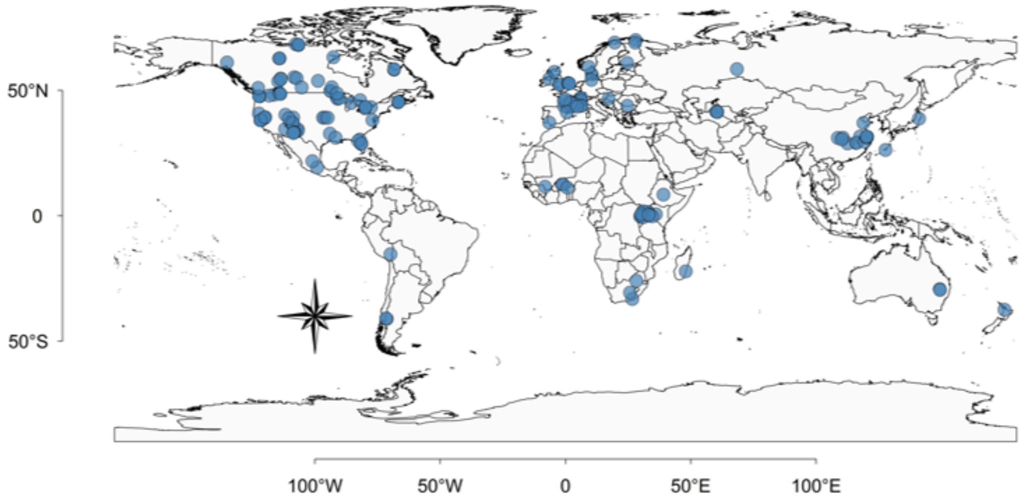

Figure A1. Spatial distribution of the local communities selected in this study.

Data sources

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Figure A2. Relationship between population SEAc and the number of sampled individuals (N_{ind}) for the 32 selected species. The number of sampled individuals for the 32 species in their native (mean = 13.0 ± 15.8SD) and introduced (mean = 13.0 ± 16.8SD) ranges is shown in the right-bottom inset. The black curve represents the fixed-effects asymptotic model fitted on the full dataset.

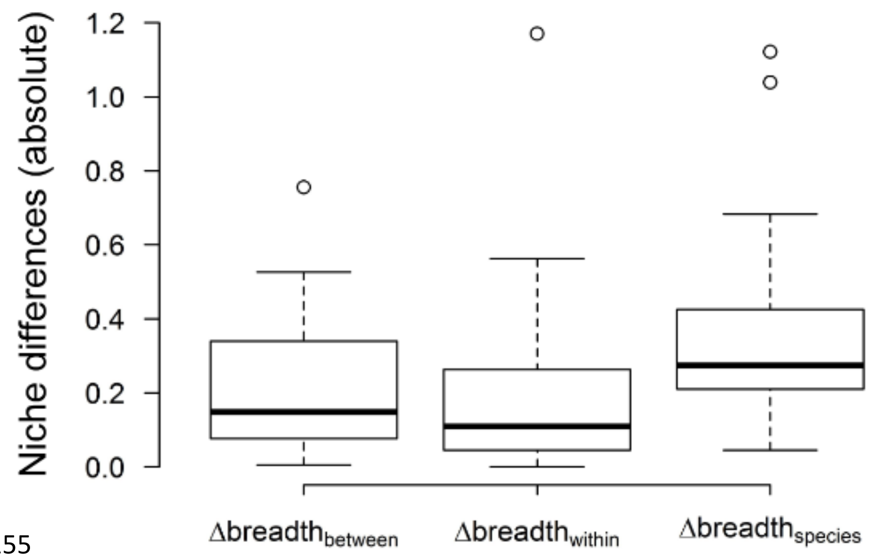

Figure A3. Comparisons of the between- versus within-ranges and across-species trophic niche differences in isotopic niche breadth using untransformed values. Within-range and across-species variability were calculated within the native range.

Characteristics of the datasets

To assess the potential limitations of our datasets in estimating native and introduced trophic niches and the magnitude of changes between ranges, we tested whether the magnitude of shifts were related to differences in the number of sampled populations and individuals between the introduced and native species ranges (i.e. unbalanced sample sizes between ranges might result in an underrepresentation of species niches and spurious niche shifts). We did not find evidence that the magnitude of shifts observed between introduced and native species ranges where associated to variation in the number of sampled populations or individuals (Fig. A3; PGLS, $P > 0.05$), suggesting that our results were not likely to be systematically biased by variation in sample sizes between ranges.

Table A1. Direction of the shifts within the $\delta^{13}C$ and $\delta^{15}N$ isotopic space with associated Rayleigh's test and concomitant mean time since introduction within the introduced range, differences in absolute latitude and species richness between the introduced and native species ranges (introduced minus native).

Scientific name	Angle 95% CI	Rayleigh's *z*	Rayleigh *P*	Time (yr)	ΔLat (°)	ΔRS
Centrarchidae						
Lepomis gibbosus	352.6-6.6	0.83	< 0.001	105.4	1.4	-2.6
Lepomis macrochirus	325.0-16.0	0.6	< 0.001	98.6	0.3	1.8
Micropterus dolomieu	283.6-7.1	0.53	0.029	109.7	2.5	0.3
Micropterus salmoides	237.0-302.4	0.45	0.001	85.7	5.2	3.8
Cichlidae						
Oreochromis niloticus	356.3-29.8	0.43	< 0.001	55.1	-2.6	1.1
Tilapia zillii	156.5-215.1	0.57	0.004	45.5	3	-3.5
Cyprinidae						
Carassius auratus	163.8-208.3	0.55	< 0.001	129	6.9	-10.7
Cyprinella lutrensis	349.0-43.1	0.54	< 0.001	36.5	-0.4	-1.9
Cyprinus carpio	238.1-260.1	0.33	< 0.001	338.4	4.9	-3.3
Notemigonus crysoleucas	213.1-30.1	0.2	0.386	115	-6.9	3.2
Pimephales promelas	350.1-103.3	0.42	0.116	50	-13.1	4.2
Pseudorasbora parva	181.9-309.6	0.37	0.35	26.5	16	-8.3
Rutilus rutilus	98.9-134.1	0.48	< 0.001	111	0.1	-0.7
Scardinius erythrophthalmus	116.6-136.7	0.78	< 0.001	36.5	-8.6	-1.4
Ictaluridae						
Ameiurus nebulosus	230.8-302.0	0.38	0.006	128	3.2	3.4
Ictalurus punctatus	68.6-89.5	0.91	< 0.001	82.3	-2.2	-2.6
Pylodictis olivaris	217.6-246.8	0.93	< 0.001	65	-3.3	-1.8
Moronidae						
Morone chrysops	122.7-160.2	0.92	0.002	55	11.5	-3
Osmeridae						
Osmerus mordax	268.9-325.4	0.61	< 0.001	79.4	3.5	0.2
Percidae						
Gymnocephalus cernua	70.8-170.1	0.37	0.064	32	-4.8	-0.5
Perca flavescens	167.7-186.8	0.63	< 0.001	117.3	-3	3.5
Sander lucioperca	329.6-226.7	0.14	0.52	123.9	-6.4	1.5
Sander vitreus	302.2-103.0	0.25	0.287	91.5	-5.5	-1
Poeciliidae						
Gambusia holbrooki	25.5-62.8	0.92	< 0.001	88	3.7	0.5
Salmonidae						

Coregonus clupeaformis	167.0-185.2	0.87	< 0.001	113.7	-13.7	5.1
Coregonus lavaretus	332.9-356.3	0.92	< 0.001	211	5.9	1.4
Oncorhynchus mykiss	135.6-174.5	0.85	< 0.001	86.4	-6.7	-2.1
Oncorhynchus nerka	223.1-277.9	0.54	< 0.001	73.8	-2	-4.6
Salmo trutta	84.6-118.6	0.85	< 0.001	121.7	-21.8	3.9
Salvelinus alpinus	16.7-121.4	0.41	0.068	67.5	-13.4	-0.1
Salvelinus fontinalis	165.6-232.6	0.52	0.003	109	-2	3.2
Salvelinus namaycush	196.2-266.5	0.15	0.015	110.7	-7.6	0.7

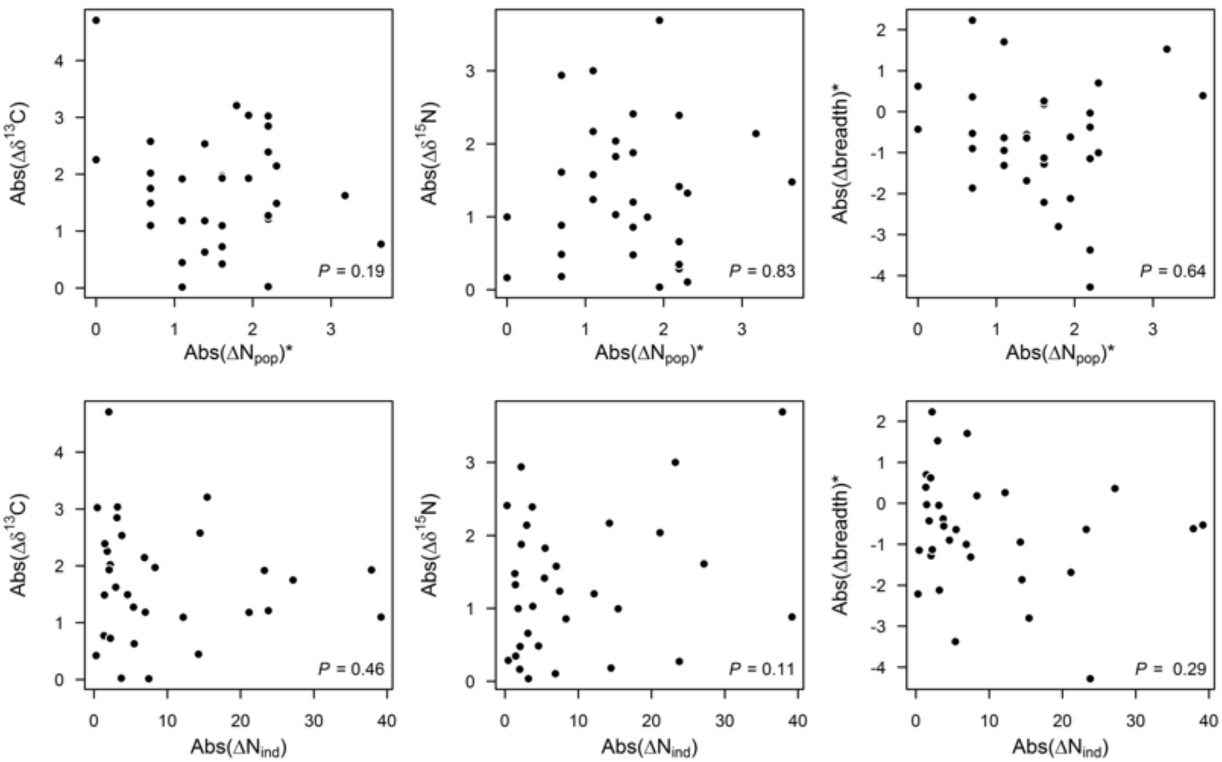

Figure A4. Relationships between the magnitudes of trophic niche shifts and the absolute differences in the number of populations (N_{pop}; top panels) or in the mean number of individuals (N_{ind}; bottom panels) between the introduced and native species ranges (introduced minus native). *P* from PGLS models. *The magnitude of changes in niche breadth and the differences in the number of populations were log-transformed to reduce skewness, resulting in negative values for species with small magnitude of change in niche breadth.

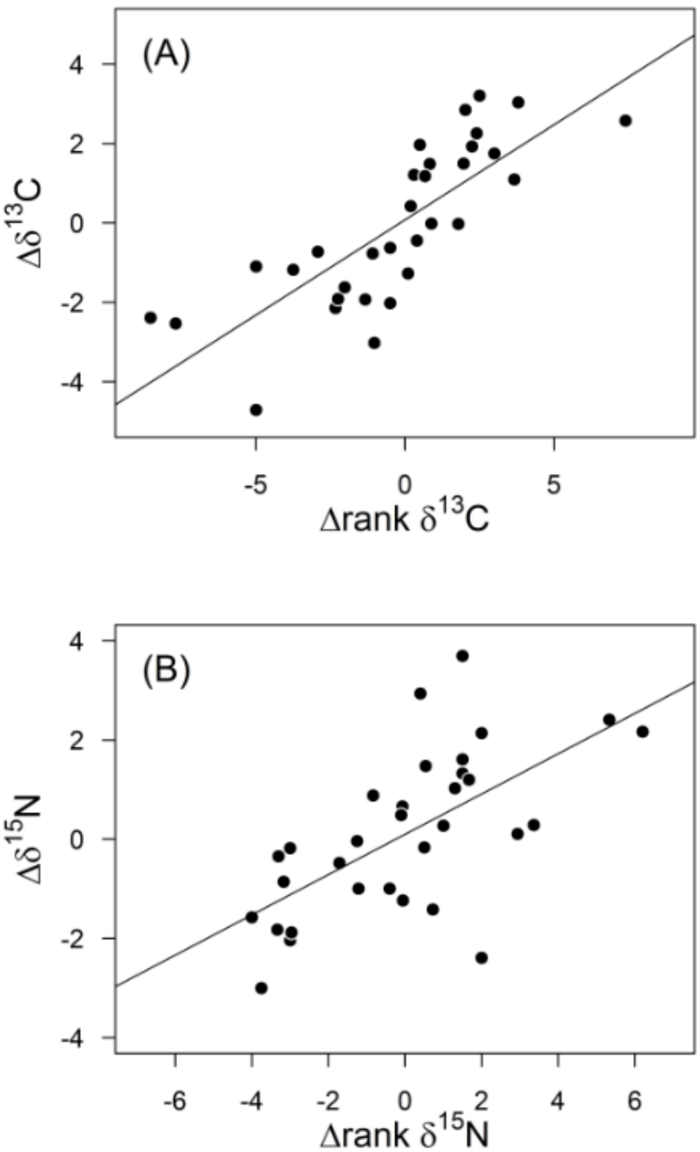

Figure A5. Shifts in $\delta^{13}C$ and $\delta^{15}N$ niche positions as a function of changes in the ordinal rank of species within communities (introduced minus native). Curves are fitted using PGLS ($P <$ 0.001).

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Appendix 3. PGLS model selection.

Table A2. Results of the PGLS model selection procedure showing the best set of models explaining the shifts in isotopic niche positions ($\Delta\delta^{13}C$ and $\Delta\delta^{15}N$): mean isotopic attributes of species in their native range ($\delta^{13}C$, $\delta^{15}N$ and niche breadth), differences in species richness (ΔSR), differences in absolute latitude (ΔLat) and time since introduction (Time). • indicates a variable that was included in the model.

	$\Delta\delta^{13}C$				$\Delta\delta^{15}N$		
	M1	*M2*	*M3*	*M4*	*M1*	*M2*	*M3*
$\delta^{13}C$	•***	•***	•**	•***			
$\delta^{15}N$					•**	•**	•**
Niche breadth						•^{NS}	
ΔSR			•^{NS}	•^{NS}			
ΔLat		•^{NS}		•^{NS}	•***	•***	•***
Time		•^{NS}					•^{NS}
R^2	0.39	0.48	0.35	0.47	0.50	0.49	0.53

$^{NS}P \geq 0.05$, $^{**}0.01 < P \leq 0.001$, $^{***}P < 0.001$

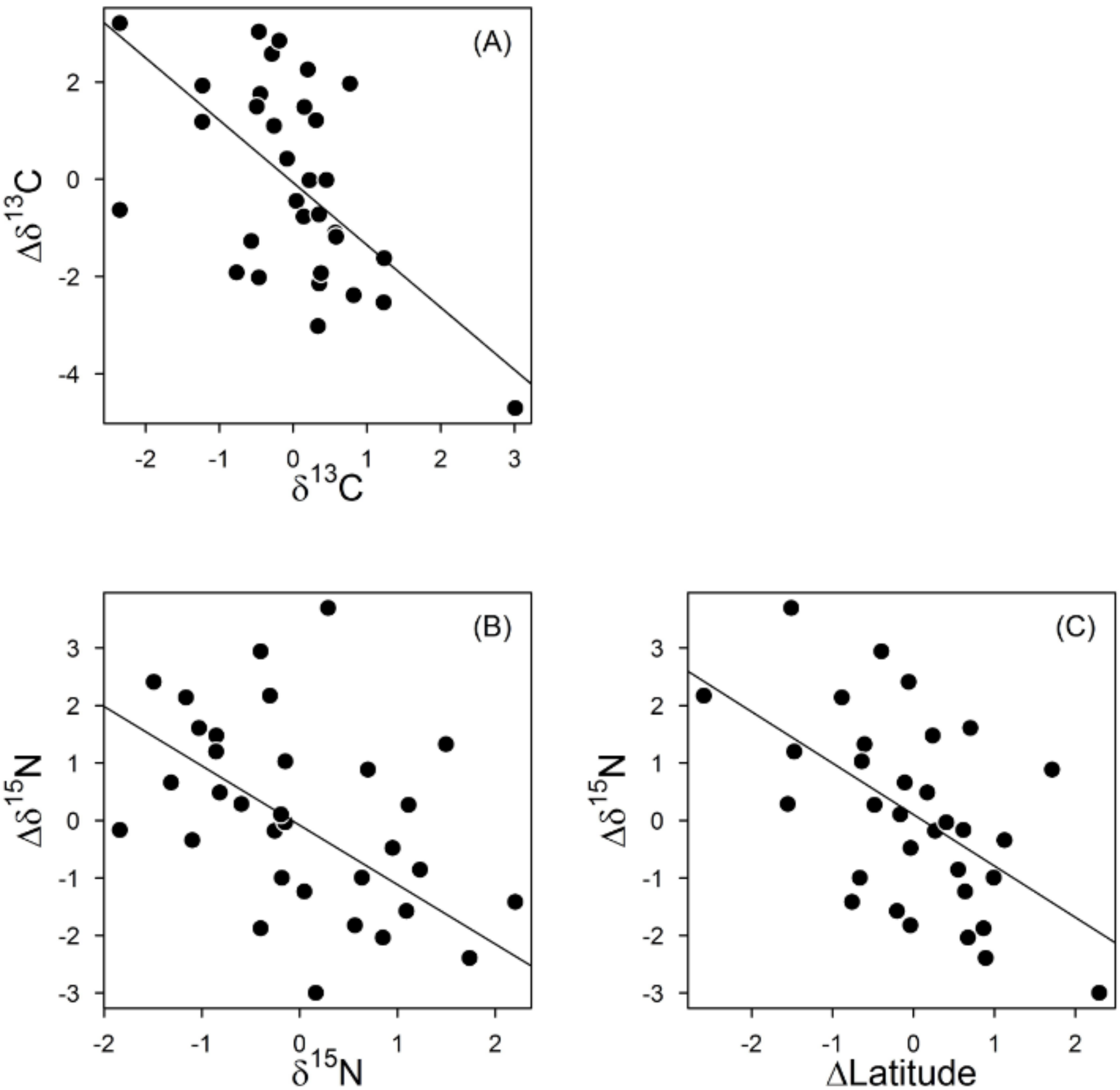

Figure A6. Shifts in (A) $\delta^{13}C$ and (B-C) $\delta^{15}N$ niche positions as a function of the best predictors identified during the model selection procedure (i.e. 95% CI that did not include zero). Curves are fitted using univariate PGLS.

Appendix 4. Comparison of niche breadth between native and nonnative species.

Differences in isotopic niche breadth between nonnative and native species were assessed using log-response ratios (Hedges et al. 1999), providing a standardized measurement of proportional differences between introduced and native populations while controlling for potential site-specific variability. Individual effects sizes and associated variances were calculated as the mean log-ratio between each introduced population and the native populations with which it co-occurred within its introduced range (178 localities × species). To test whether niche breadth of nonnative species differed from those of native species (i.e. whether the mean effect size differed significantly from zero), we then used a linear mixed model meta-analytical approach using species identity as a grouping factor and weighted the individual effects sizes by the inverse of their corresponding standard errors [*nlme* package in R; Pinheiro et al. (2015)]. This approach allows comparison of non-independent effect sizes while increasing the precision of the combined estimates by taking into account unequal variation and sample sizes between effect sizes (Mengersen and Schmid 2013). We repeated this procedure using only co-occurring native species that have not been reported as being established outside of their native range according to FishBase (Froese and Pauly 2015).

We found that the isotopic niche breadth of the 32 selected nonnative species did not differ from those of native species with which they co-occurred within their introduced range, even after excluding native species that are known to have been introduced outside of their native range (Fig. A6). However, this last result should be interpreted with caution due to the low sample sizes involved in the comparison between introduced populations and populations of species that have never been introduced outside of their native ranges. Nonetheless, we found a large variability across nonnative species, suggesting that understanding the success of nonnative species may benefit from a more detailed examination of such differences. For instance, a dataset encompassing a larger sets of introductions may allow to investigate how differences in niche breadth associate with success from species introduction to spread.

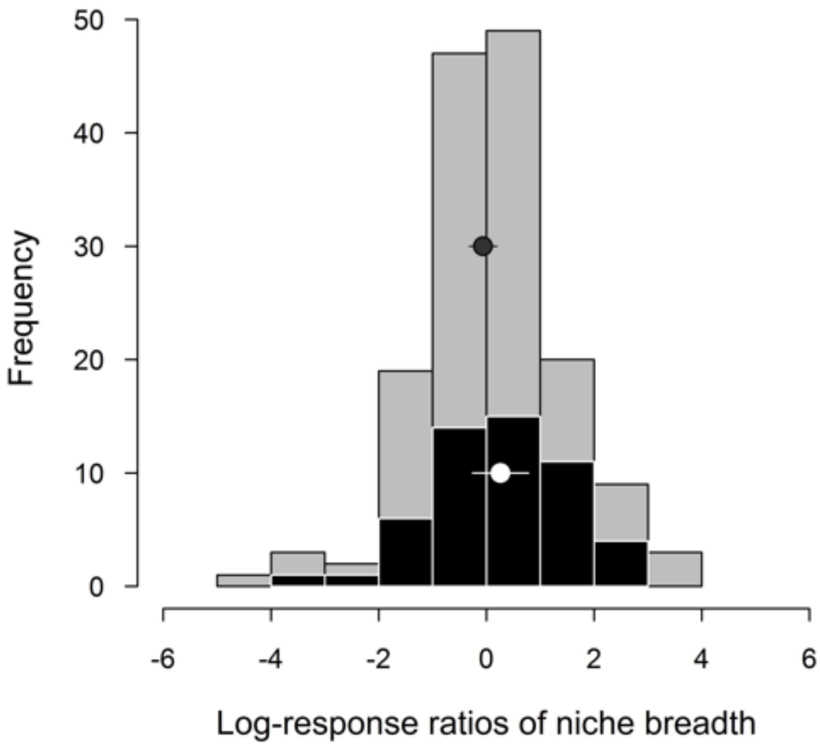

Figure A7. Log-response ratios of isotopic niche breadth between the 32 nonnative species and the native species with which they co-occurred within their introduced ranges [log(nonnative / native)]: grey bars represent individual log-response ratios calculated with all co-occurring native populations and black represent individual log-response ratios calculated with only native populations of species that have never been established outside of their native ranges. Dots indicate mean log-response ratios and 95% confidence interval (grey: with all native co-occurring species; white: with only species that have never been established outside of their native ranges).

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Appendix 5. Non-phylogenetic analyses.

To assess the influence of our methodological framework on the results, we also performed non-phylogenetic analyses. As previously, we found little evidence for trophic niche conservatism of freshwater fishes across the globe. The magnitude of shifts was comparable along the δ^{13}C and the δ^{15}N axes (paired t-test, $P = 0.19$). Again, we did not find evidence that niche shifts were related to variation in sample size between the introduced and native ranges (all $P > 0.05$ using linear models). Further, we found that shifts in isotopic niche positions were associated with changes in the rank occupied by the species along their respective isotopic dimensions, expressed as either ordinal (linear models, $R^2 = 0.68$ and 0.61, $P < 0.001$) or relative rank (linear models, $R^2 = 0.61$ and 0.39, $P < 0.001$). In contrast, we found that the relationships between shifts in isotopic niche positions and niche breadth were not statistically significant for δ^{13}C ($P = 0.80$) and δ^{15}N ($P = 0.07$) (linear models), suggesting that niche shifts were not directly driven by changes in intraspecific trophic variability.

The magnitude of shifts in isotopic niche positions from native to introduced ranges exceeded the observed variability across sites within the native range along both δ^{13}C and δ^{15}N axes (paired *t*-test, $P < 0.001$), and were comparable to the differences observed with co-occurring species (paired *t*-test, $P = 0.13$ and $P = 0.66$). By contrast, the magnitude of changes in niche breadth was not different from the degree of variability observed within the native range (paired *t*-test, $P = 0.19$) or with co-occurring species (paired *t*-test, $P = 0.18$).

As with the phylogenetic analyses, we found that niche shifts along the δ^{13}C (four selected models, $R^2 = 0.27$-0.32; Table A3) and δ^{15}N (three selected models, $R^2 = 0.43$-0.44; Table A3) axes were significantly and negatively associated with the mean δ^{13}C and δ^{15}N values of species in their native range, respectively, while differences in mean absolute latitude were also significantly and negatively associated to shifts along the δ15N axis.

Table A3. Results of the model selection procedure using simple linear models showing the best set of models explaining the shifts in isotopic niche positions ($\Delta\delta^{13}C$ and $\Delta\delta^{15}N$): mean isotopic attributes of species in their native range ($\delta^{13}C$, $\delta^{15}N$ and niche breadth), differences in species richness (ΔSR), differences in absolute latitude (ΔLat) and time since introduction (Time). • indicates a variable that was included in the model.

	$\Delta\delta^{13}C$				$\Delta\delta^{15}N$		
	M1	*M2*	*M3*	*M4*	*M1*	*M2*	*M3*
$\delta^{13}C$	$\bullet^{**}$	$\bullet^{**}$	$\bullet^{**}$	$\bullet^{**}$			
$\delta^{15}N$					$\bullet^{**}$	$\bullet^{*}$	$\bullet^{**}$
Niche breadth							$\bullet^{NS}$
ΔSR	$\bullet^{NS}$		$\bullet^{NS}$				
ΔLat					$\bullet^{***}$	$\bullet^{***}$	$\bullet^{***}$
Time				$\bullet^{NS}$		$\bullet^{NS}$	
$\delta^{13}C \times \Delta SR$			$\bullet^{NS}$				
$\delta^{13}C \times \Delta Lat$							
$\delta^{13}C \times$ Time							
$\delta^{15}N \times \Delta SR$							
$\delta^{15}N \times \Delta Lat$							
$\delta^{15}N \times$ Time							
R^2	0.31	0.27	0.32	0.28	0.43	0.44	0.44

$^{NS}P \geq 0.05$, $^{*}0.01 \leq P < 0.05$, $^{**}0.01 < P \leq 0.001$, $^{***}P < 0.001$