**Supplemental Material I**

**Table S1.** Main prey of CCE predators, as indicated by >20% by mass or number in the diet. See text for location abbreviations.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Predator | Site | Anchovy | Sardine | Market squid | Juv. rockfish | Other | Source |
| Common murre | SFI | x |  | x | x |  | Sydeman et al*.* 2001, 2009 |
| Rhinoceros auklet | SFI | x |  | x | x |  | Thayer & Sydeman 2007 |
| ANI | x |  | x | x |  | Thayer & Sydeman 2007 |
| Brandt’s cormorant | SFI | x |  |  | x | sanddab (*Citharicthys* sp.) | Ainley et al*.* 1981, Elliott et al*.* 2015 |
| ANI | x |  |  | x | sanddab (*Citharicthys* sp.) | J. Thayer et al*.* unpublished data |
| ALCZ | x |  |  | x | sanddab (*Citharicthys* sp.) | Yakich 2005 |
| Pelagic cormorant | SFI |  |  |  | x | sculpin (Cottidae) | Ainley et al*.* 1981 |
| ANI |  |  |  | x | sculpin (Cottidae) | J. Thayer et al*.* unpublished data |
| Pigeon guillemot | SFI |  |  |  | x | sculpin (Cottidae) | Sydeman et al*.* 2001 |
| Brown pelican | SBI | x | x |  |  |  | Sunada et al*.* 1980, Gress et al*.* 1980, Harvey & Gress 2008 |
| ANA | x | x |  |  |  |
| Least tern | VB | x |  |  |  | silversides (Atherinidae) | Atwood & Kelly 1984 |
| California sea lion \* | SCI | x | x | x |  |  | Lowry et al*.* 1991, 1999, Antonelis et al*.* 1990; Melin et al. 2012 |
| SBI | x | x | x |  |  |
| SMI | x | x | x |  |  |
| SNI | x | x | x |  |  |
| Chinook salmon | CV | x | x | x | x | krill (Euphausiidae) | Thayer et al*.* 2014, Hunt et al. 1999, Merkel 1957 |

*\* For CASL in the southern CCE, only % frequency of occurrence of prey in the diet was available, so main prey represent > 40% of %FO.*

**Table S2.** Individual predator-prey relationships for marine birds, mammals and fish in the central and southern CCE, preying on

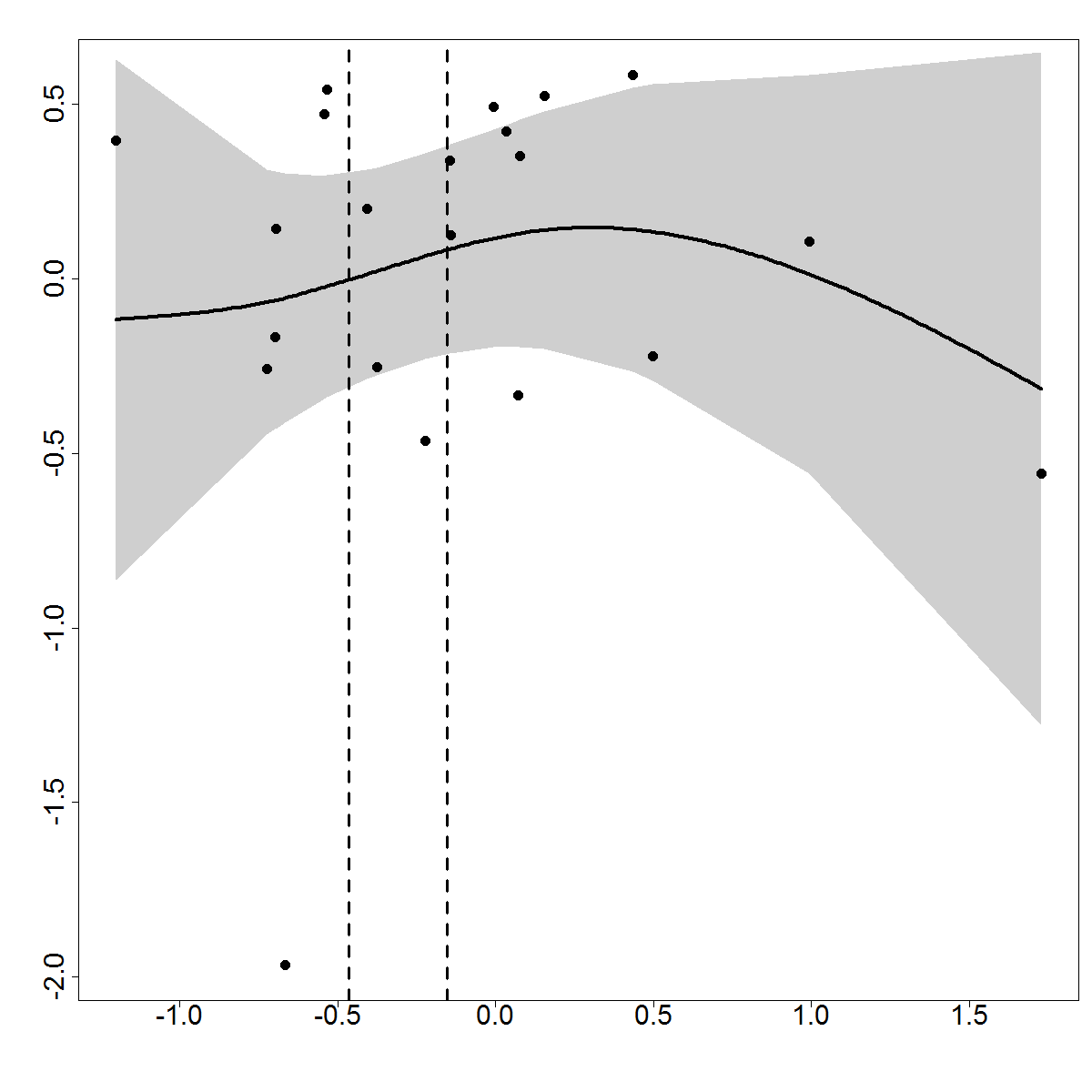
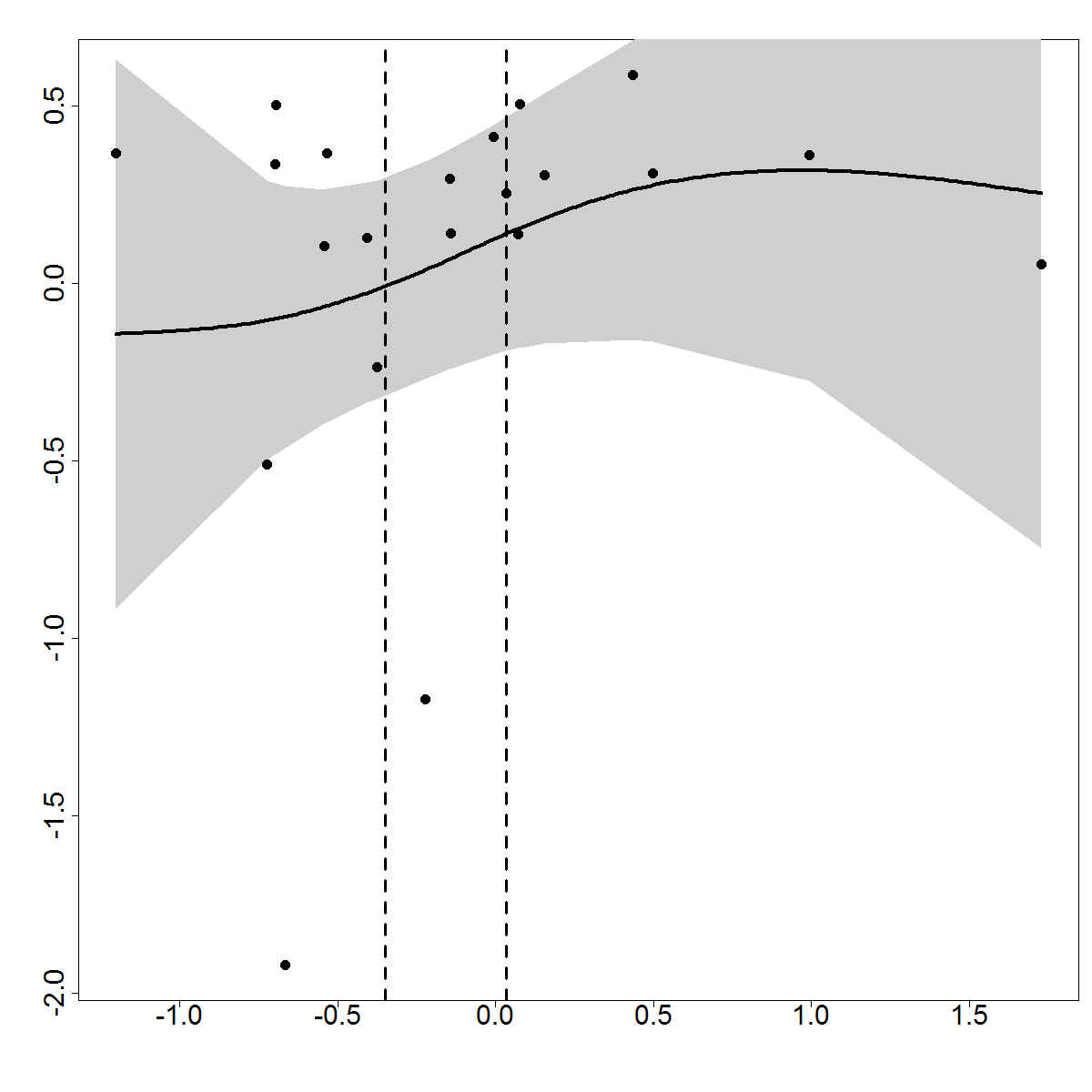
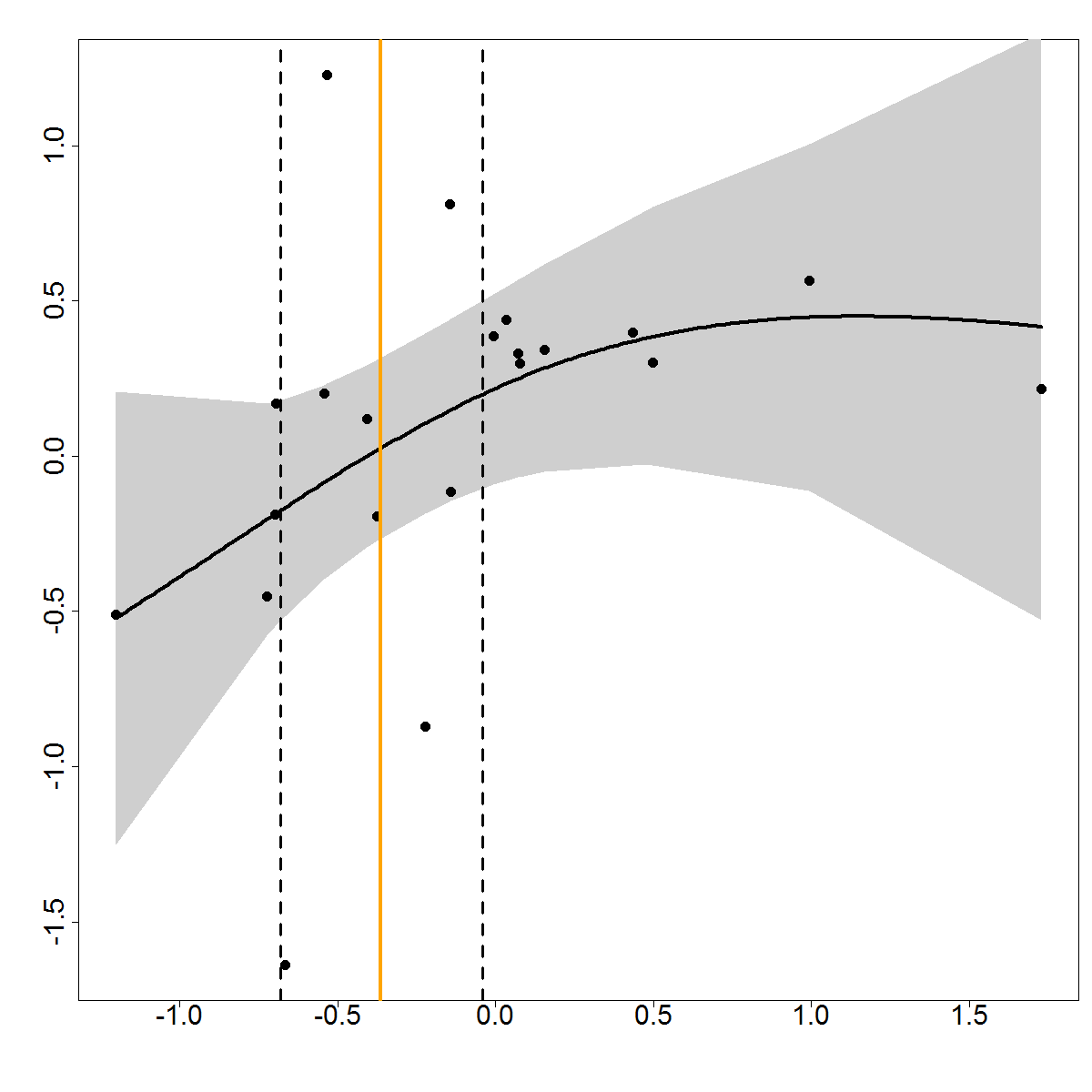
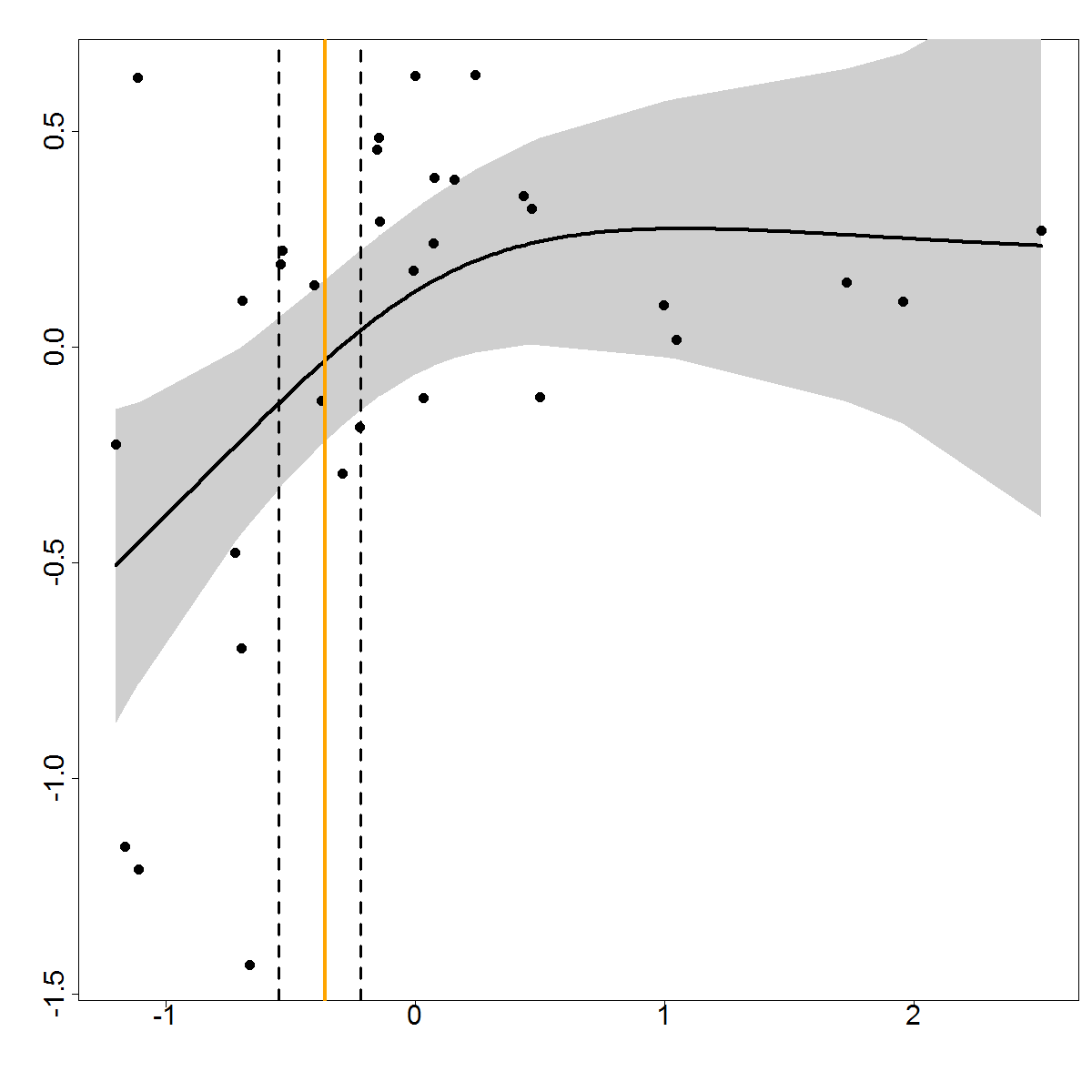
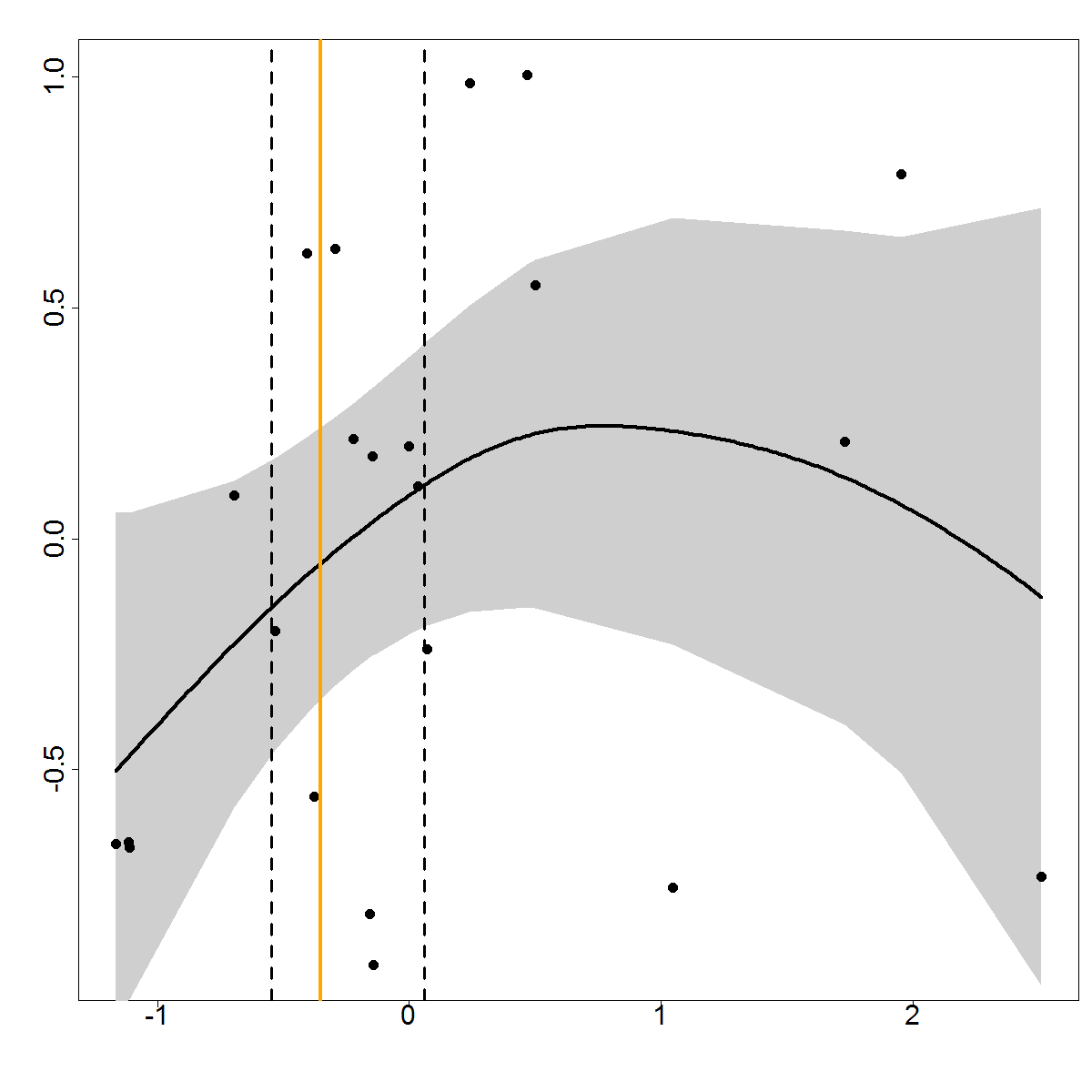
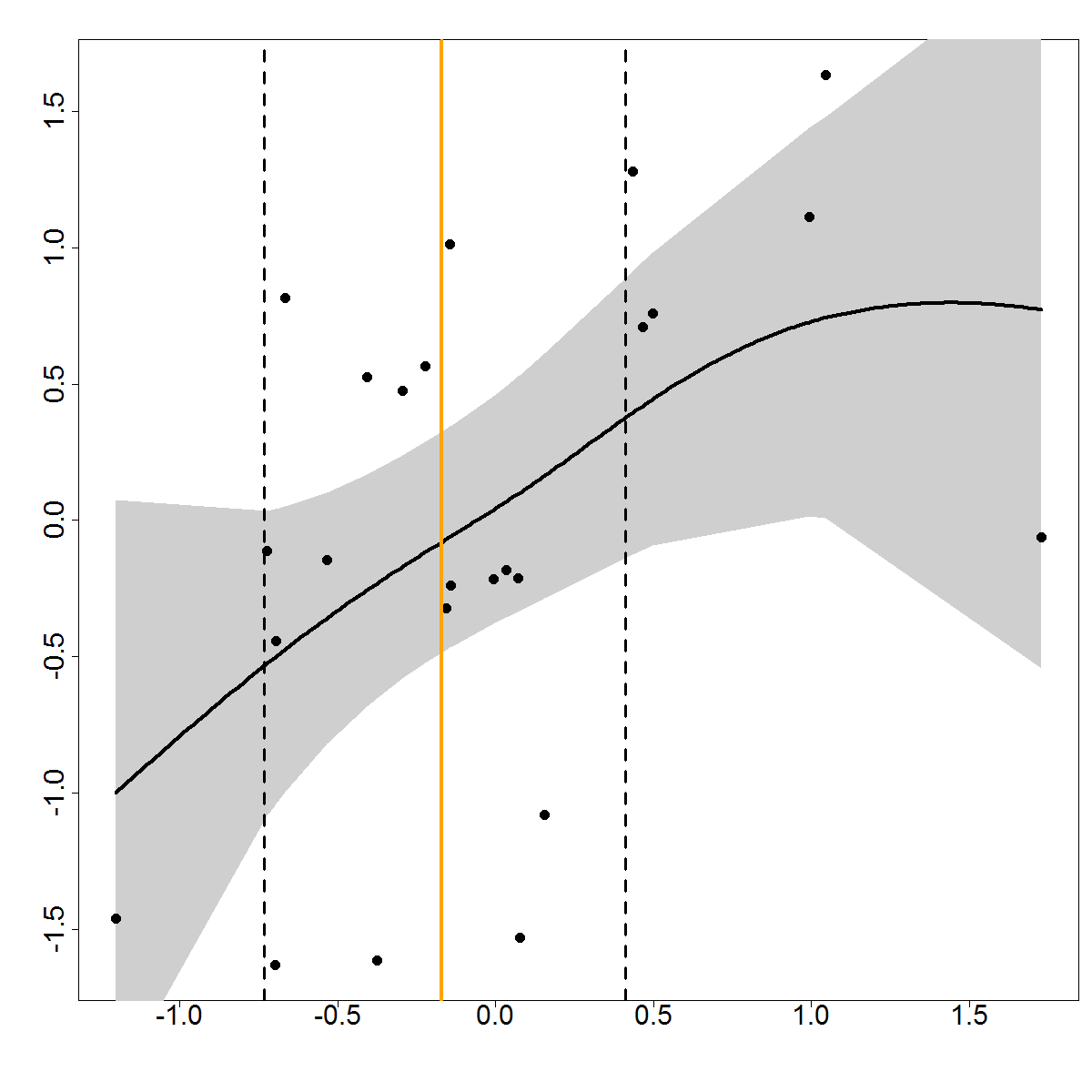
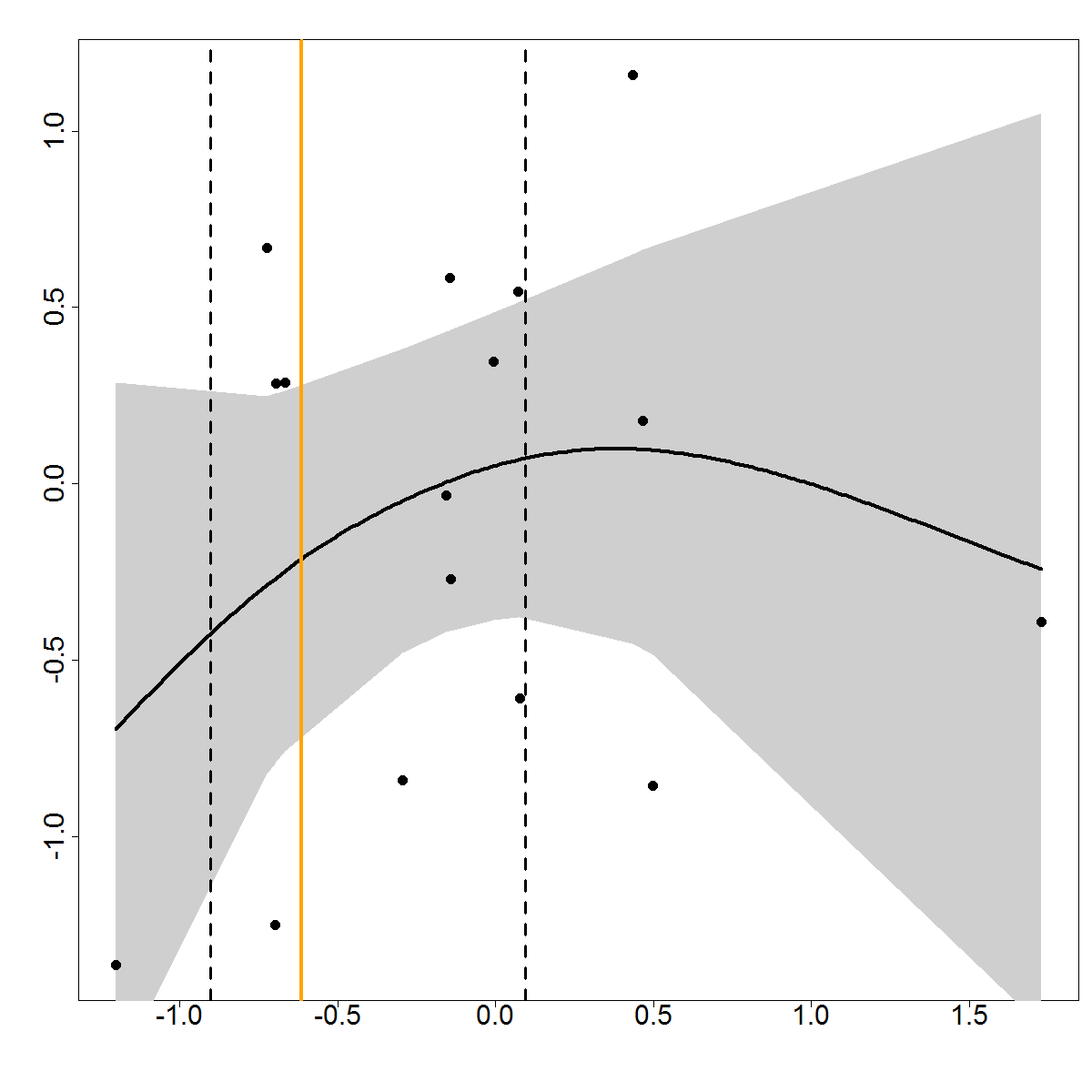
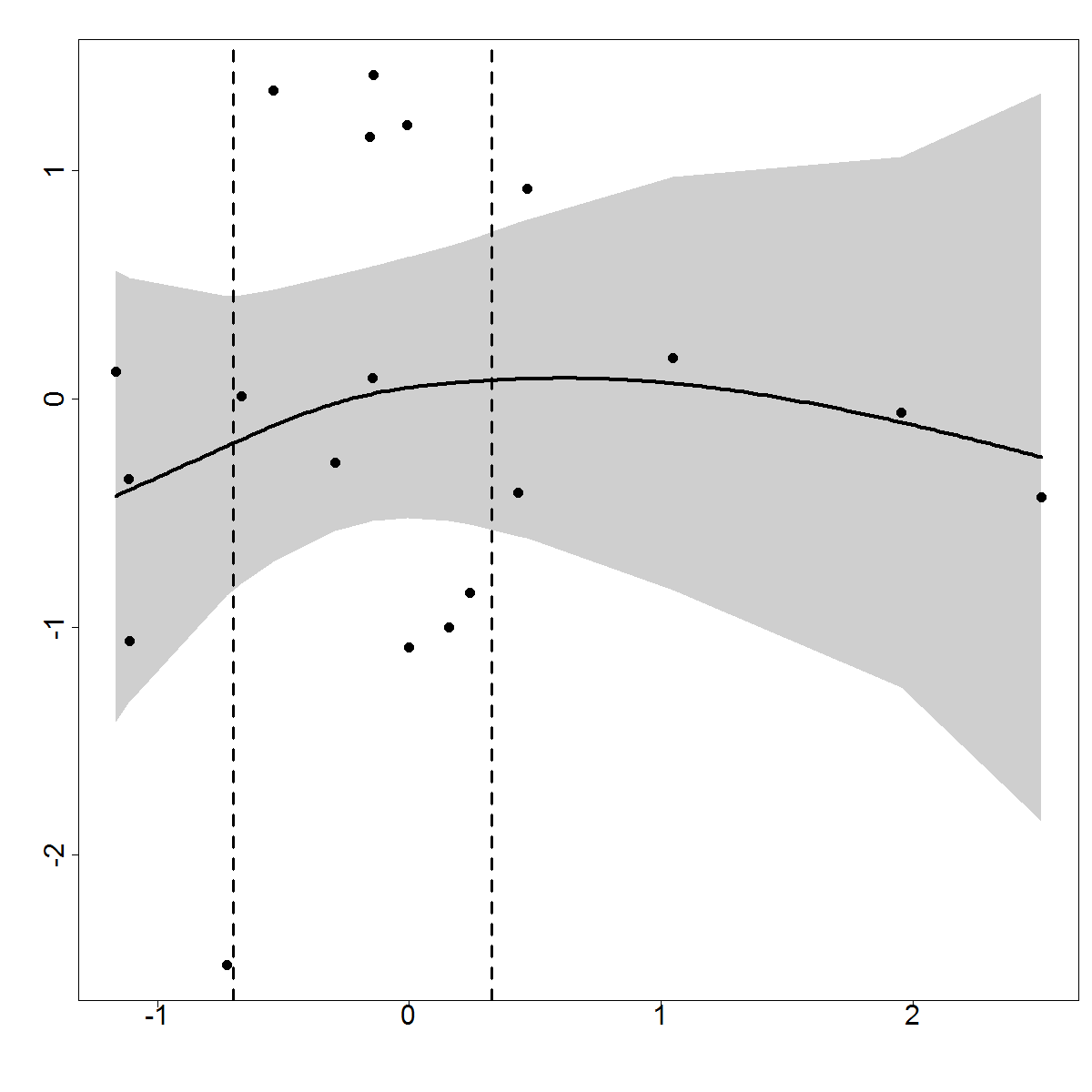
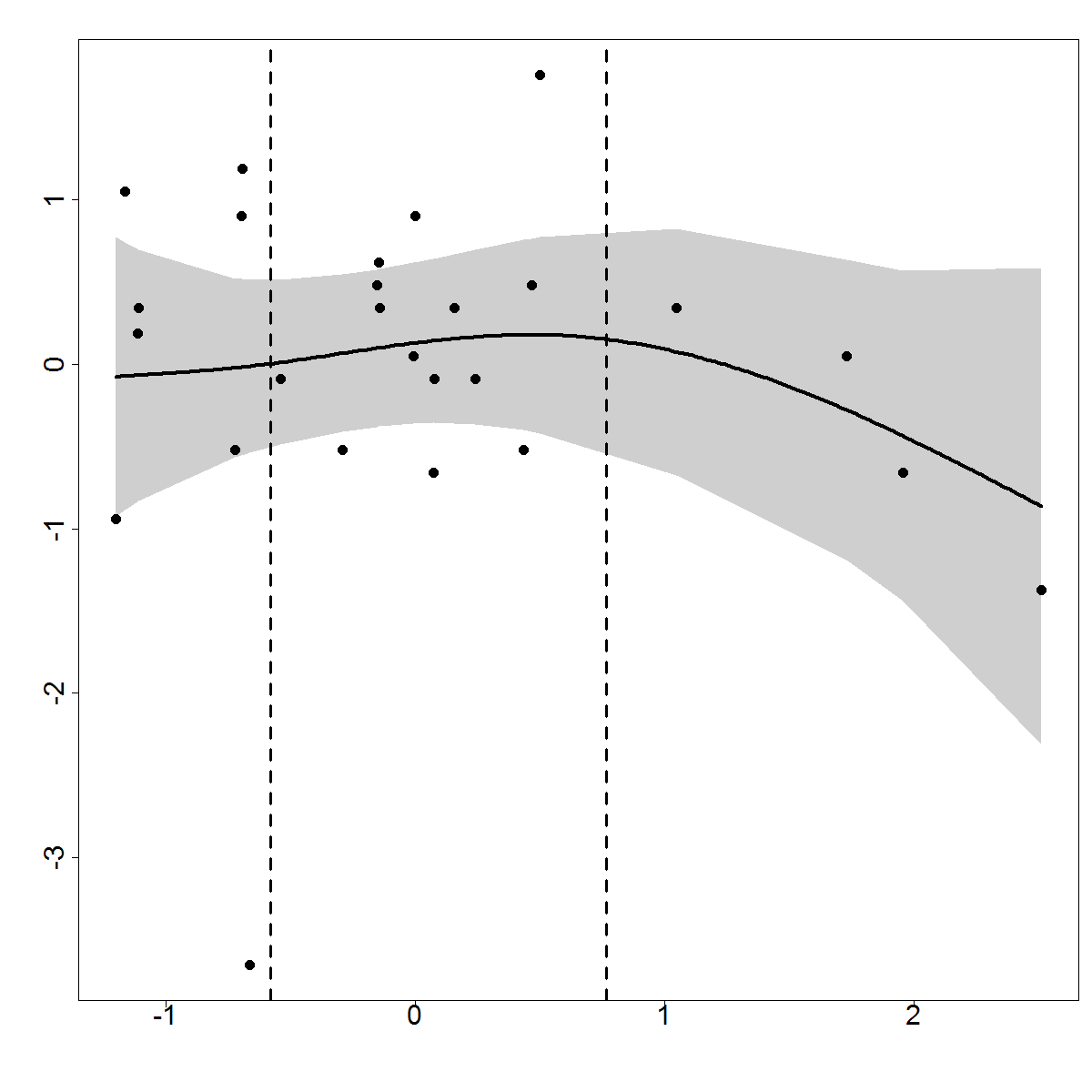
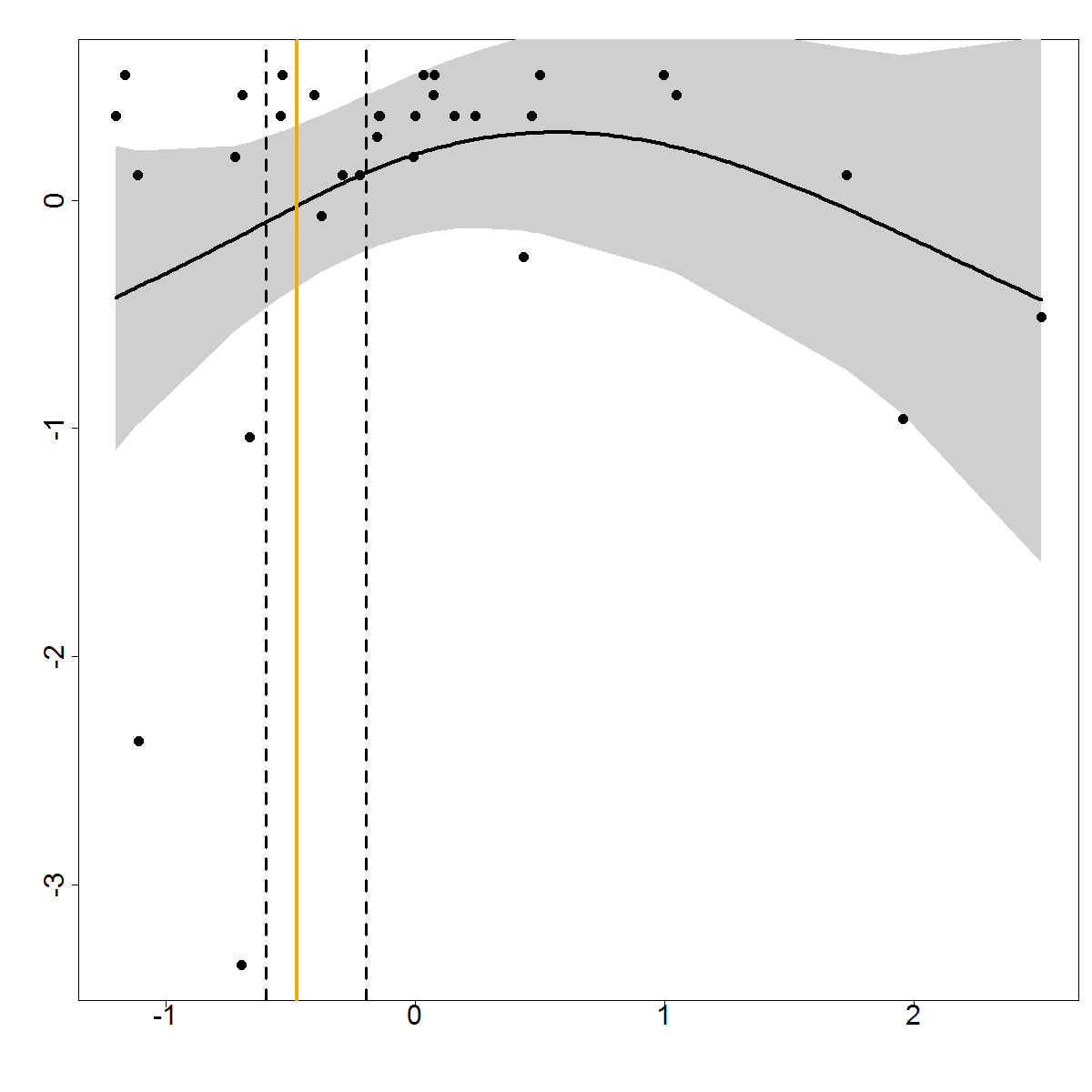
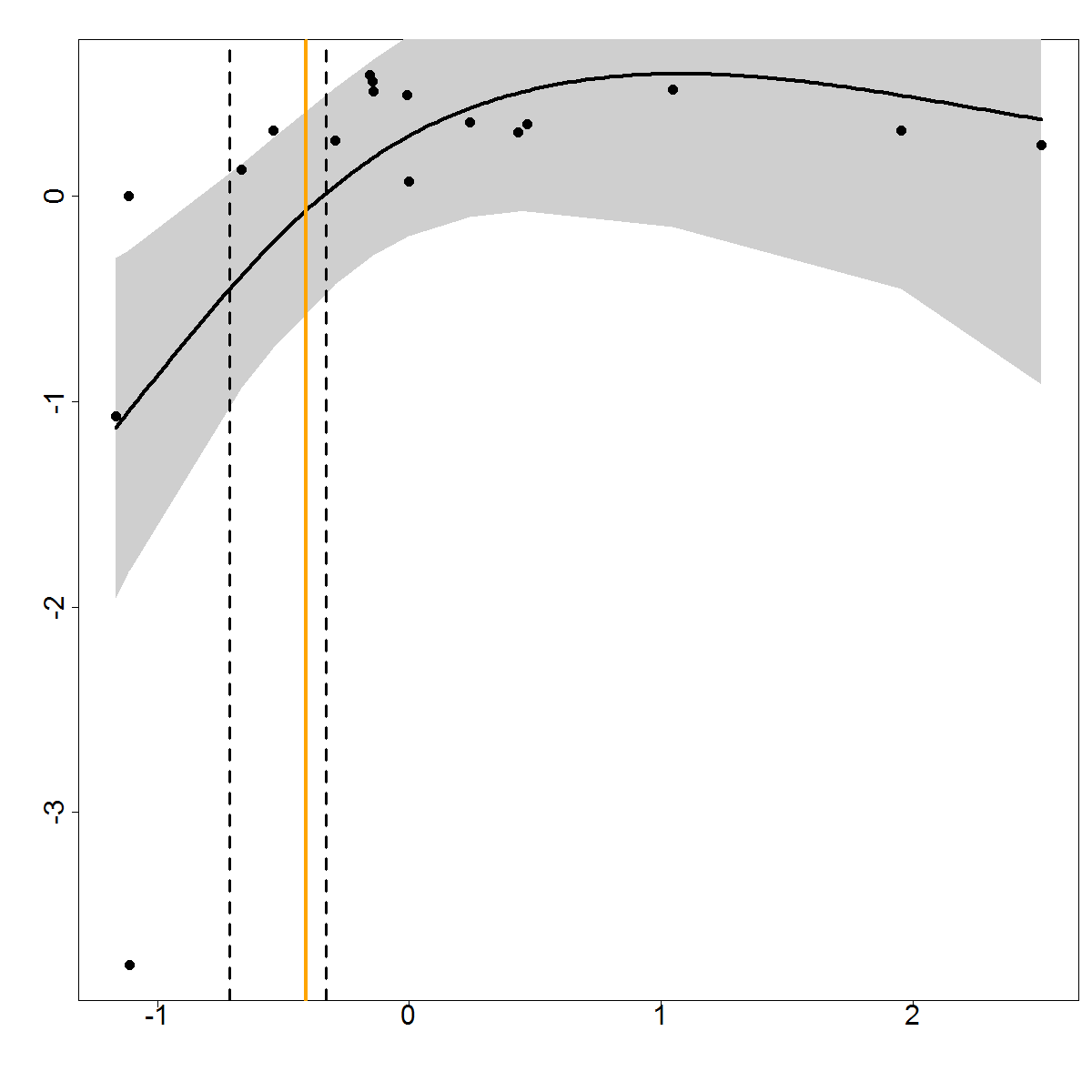
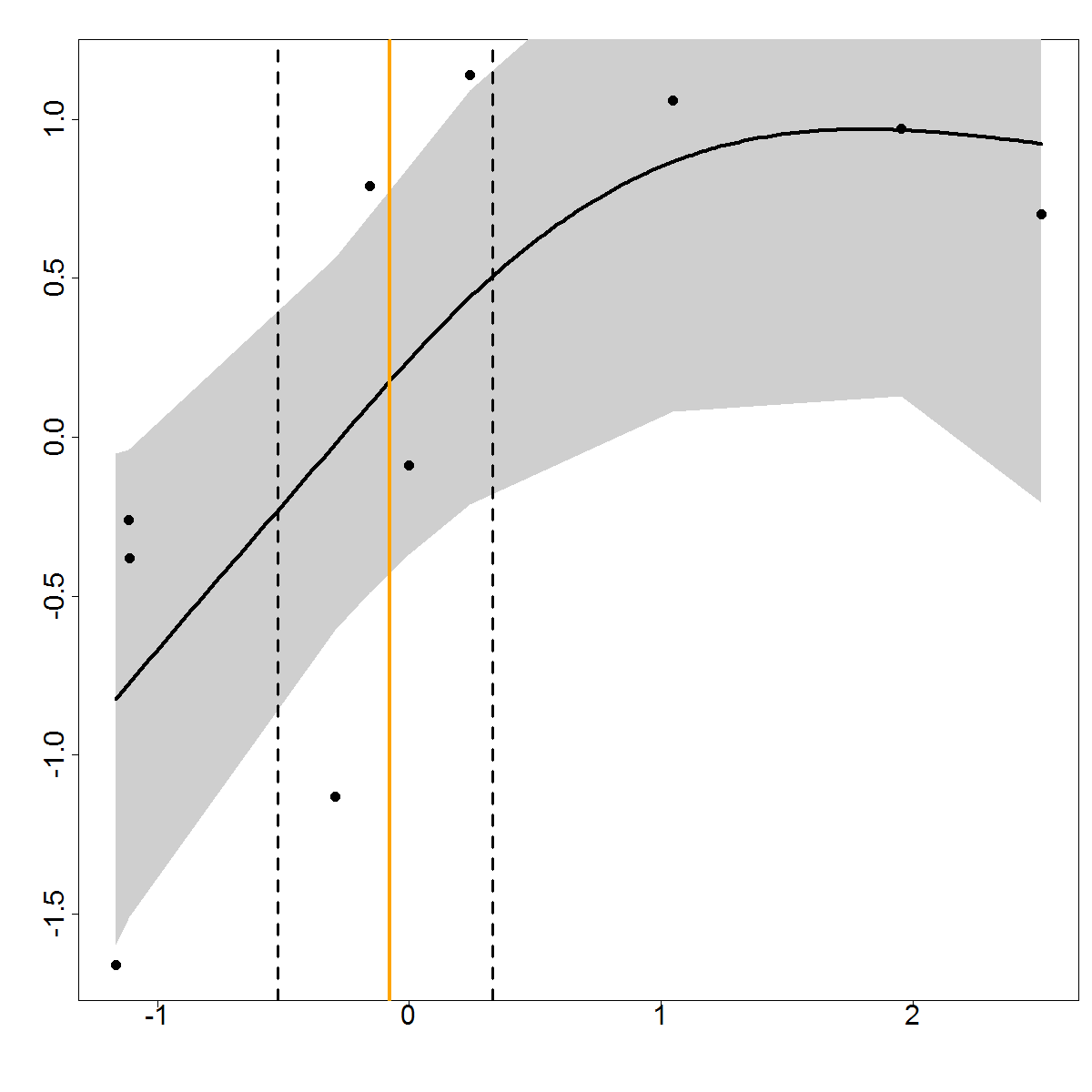
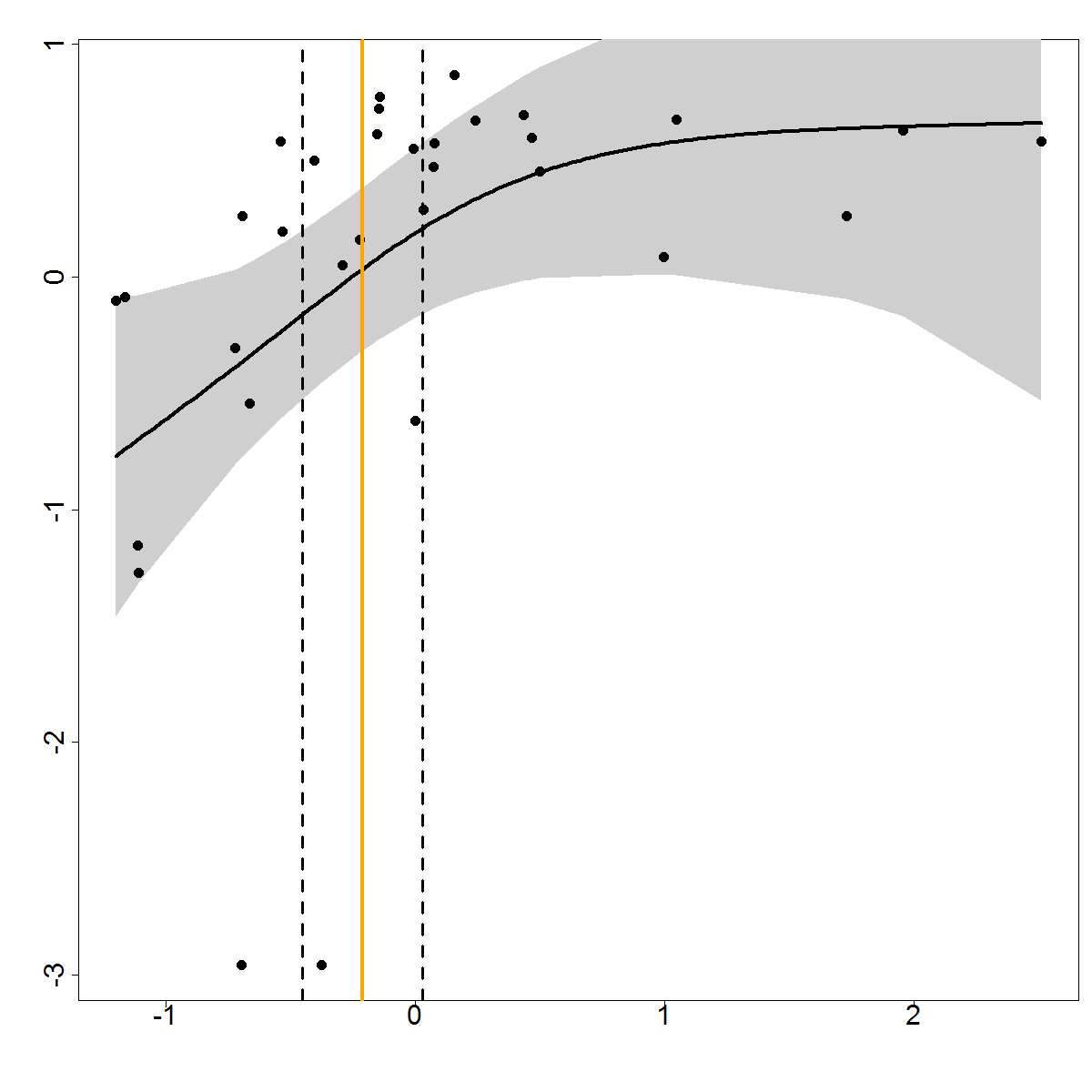
northern anchovy, Pacific sardine, juvenile rockfish and market squid.1 See Table 1 for predator indexdefinitions.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Predator** |  | | **Region** | **Specific location** | | **Predator index** | | **1˚ prey threshold** | | **Years modeled** | | **N spp-yrs** | |
| **1˚ prey** | |
|  | **Anchovy** | |  |  | |  | |  | |  | | **292** | |
| Brandt's cormorant | Anchovy | | central CA | SE Farallon Isl. | | RS | | -0.20 (27%) | | 1975-2011 | | 32 | |
| Brandt's cormorant | Anchovy | | central CA | Año Nuevo Isl. | | RS | | -0.08 (30%) | | 2002-2011 | | 10 | |
| Brandt's cormorant | Anchovy | | central CA | Alcatraz Isl. | | RS | | -0.41 (21%) | | 1995-2011 | | 17 | |
| Common murre | Anchovy | | central CA | SE Farallon Isl. | | RS | | -0.48 (20%) | | 1975-2011 | | 32 | |
| Rhinoceros auklet | Anchovy | | central CA | SE Farallon Isl. | | RS | | no threshold\* | | 1986-2013 | | 28 | |
| Rhinoceros auklet | Anchovy | | central CA | Año Nuevo Isl. | | RS | | no threshold\* | | 1994-2013 | | 20 | |
| Brown pelican | Anchovy | | southern CA | Anacapa Isl. | | RS | | -0.17 (~35%) | | 1975-2004 | | 24 | |
| Brown pelican | Anchovy | | southern CA | Santa Barbara Isl. | | RS | | -0.61 (~20%) | | 1986-2003 | | 16 | |
| Least tern | Anchovy | | southern CA | Venice Beach | | RS\* | | -0.35 (~22%) | | 1978-2011 | | 22 | |
| CA sea lion | Anchovy | | southern CA | San Clemente Isl. | | Pup | | -0.36 (~29%) | | 1975-2000 | | 21 | |
| CA sea lion | Anchovy | | southern CA | Santa Barbara Isl. | | Pup | | no threshold\* | | 1975-2000 | | 21 | |
| CA sea lion | Anchovy | | southern CA | San Miguel Isl. | | Pup | | -0.36 (~23%) | | 1975-2011 | | 32 | |
| CA sea lion | Anchovy | | southern CA | San Nicolas Isl. | | Pup | | no threshold\* | | 1975-2000 | | 21 | |
|  | **Rockfish (juv.)** | |  |  | |  | |  | |  | | **182** | |
| Common murre | Rockfish (juv.) | | central CA | SE Farallon Isl. | | RS | | -0.21 (~41%) | | 1983-2013 | | 31 | |
| Rhinoceros auklet | Rockfish (juv.) | | central CA | SE Farallon Isl. | | RS | | -0.93 (~25%) | | 1986-2013 | | 28 | |
| Rhinoceros auklet | Rockfish (juv.) | | central CA | Año Nuevo Isl. | | RS | | no threshold\* | | 1994-2013 | | 20 | |
| Pigeon guillemot | Rockfish (juv.) | | central CA | SE Farallon Isl. | | RS | | -0.72 (~30%) | | 1983-2013 | | 31 | |
| Pelagic cormorant | Rockfish (juv.) | | central CA | SE Farallon Isl. | | RS | | -0.98 (~24%) | | 1983-2013 | | 31 | |
| Pelagic cormorant | Rockfish (juv.) | | central CA | Año Nuevo Isl. | | RS | | -1.4 (~25%) | | 1996-2012 | | 17 | |
| Chinook salmon | Rockfish (juv.) | | central CA | Central Valley | | Returns | | -0.83 (~27%) | | 1983-2006 | | 24 | |
| **Predator** |  | **Region** | | | **Specific location** | | **Predator index** | | **1˚ prey threshold** | | **Years modeled** | | **N spp-yrs** | |
| **1˚ prey** |
|  | **Sardine** |  | | |  | |  | |  | |  | | **79** | |
| Brown pelican | Sardine | southern CA | | | Anacapa Isl. | | RS | | *not enough obs* | | 1992-2004 | | 11 | |
| Brown pelican | Sardine | southern CA | | | Santa Barbara Isl. | | RS | | *not enough obs* | | 1992-2003 | | 10 | |
| CA sea lion | Sardine | southern CA | | | San Clemente Isl. | | Pup | | *not enough obs* | | 1992-2000 | | 8 | |
| CA sea lion | Sardine | southern CA | | | Santa Barbara Isl. | | Pup | | *not enough obs* | | 1992-2000 | | 8 | |
| CA sea lion | Sardine | southern CA | | | San Miguel Isl. | | Pup | | -0.39 (~29%) | | 1992-2011 | | 19 | |
| CA sea lion | Sardine | southern CA | | | San Nicolas Isl. | | Pup | | *not enough obs* | | 1992-2000 | | 8 | |
| Chinook salmon | Sardine | central CA | | | Central Valley | | Returns | | -0.31 (31%) | | 1992-2006 | | 15 | |
|  | **Market squid** |  | | |  | |  | |  | |  | | **72** | |
| CA sea lion | Market squid | southern CA | | | San Clemente Isl. | | Pup | | *not enough obs* | | 1997-2000 | | 4 | |
| CA sea lion | Market squid | southern CA | | | Santa Barbara Isl. | | Pup | | *not enough obs* | | 1997-2000 | | 4 | |
| CA sea lion | Market squid | southern CA | | | San Miguel Isl. | | Pup | | -0.73 (~22%) | | 1997-2011 | | 15 | |
| CA sea lion | Market squid | southern CA | | | San Nicolas Isl. | | Pup | | *not enough obs* | | 1997-2000 | | 4 | |
| Common murre | Market squid | central CA | | | SE Farallon Isl. | | RS | | -0.70 (~23%) | | 1997-2011 | | 15 | |
| Rhinoceros auklet | Market squid | central CA | | | SE Farallon Isl. | | RS | | -0.34 (~34%) | | 1997-2011 | | 15 | |
| Rhinoceros auklet | Market squid | central CA | | | Año Nuevo Isl. | | RS | | -0.37 (~33%) | | 1997-2011 | | 15 | |

*\* In all cases for which there were sufficient observations but the model did not converge to calculate a threshold, data in the upper left quadrant of curve, when prey abundance was high yet predator productivity was low, signaled alternate prey use precluding a significant relationship with just one prey species.*

1 Data sources in the central CCE included Garcia-Reyes et al. 2013, Leising et al*.* 2014, Elliott et al*.* 2015, and Point Blue Conservation Science/US Fish & Wildlife Service unpublished report (Warzybok et al*.* 2014) for SE Farallon Island seabirds; Thayer and Sydeman 2007, Garcia-Reyes et al. 2013, Carle et al*.* 2014, Oikonos unpublished report (Carle et al*.* 2014), and J. Thayer unpublished data for Año Nuevo Island seabirds; Saenz et al*.* 2006 and Farallon Institute/National Park Service (NPS) unpublished report (Robinson et al*.* 2014) for Alcatraz Island seabirds; Kilduff et al*.* 2014 and P. Kilduff unpublished data for Chinook salmon. Central CCE prey data came from the National Marine Fisheries Service SWFSC Rockfish Recruitment and Ecosystem Assessment Survey (J. Field and K. Sakuma/NOAA; also see Ralston et al*.* 2014, Davison et al*.* in prep). Southern CCE data sources included Lowry and Maravilla 2005, Melin et al. 2012, and Caretta et al*.* 2014 for Channel Islands sea lions; California Department of Fish & Wildlife (CDFW) unpublished report (Burkett et al*.* 2007), Sutil Conservation Ecology/NPS unpublished report (Harvey and Mazurkiewicz 2014), and F. Gress unpublished data for Channel Islands brown pelicans; Massey et al*.* 1992, H.T. Harvey & Associates/US Army Corps Engineers unpublished report (Burton and Terrill 2012), and CDFW unpublished report (Frost 2014) for least terns. Southern CCE prey data came from CalCOFI surveys (S. McClatchie and E. Weber/NOAA; also see Smith and Moser 2003, Koslow et al*.* 2011, MacCall et al*.* 2015, Davison et al*.* in prep).

**Figure S1.** Relationships of individual predator productivity with prey abundance at distinct locations throughout the central/southern CCS. All x-axes represent prey abundance, while all y-axes represent predator productivity. Abundance of **I)** anchovy prey relative to productivity of a) Brandt’s cormorants at SE Farallon Island (SFI), b) Año Nuevo Island (ANI) and c) Alcatraz Island (ALZ), d) common murre at SFI, e) rhinoceros auklet at SFI and f) ANI, g) brown pelican at Santa Barbara Island (SBI) and h) Anacapa Island (ANA), i) least tern at Venice Beach (VB), and j) California sea lions at San Miguel Island (SMI) k) San Clemente Island (SCI), l) SBI, and m) San Nicolas Island (SNI); **II)** juvenile rockfish prey relative to productivity of a) common murre at SFI, b) rhinoceros auklet at SFI and c) ANI, d) pelagic cormorant at SFI and e) ANI, f) pigeon guillemot at SFI, and g) Chinook salmon from the Central Valley fall run (CV). **III)** sardine prey relative to a) productivity of sea lions at (SMI) and b) Chinook salmon from CV; and **IV)** market squid prey relative to productivity of a) common murre at SFI, b) rhinoceros auklet at SFI and c) ANI, and d) sea lions at SMI. As in Table A2, in all cases for which there were sufficient observations but the model did not converge to calculate a threshold, data in the upper left quadrant of curve, when prey abundance was high yet predator productivity was low, signaled alternate prey use precluding a significant relationship with just one prey species.



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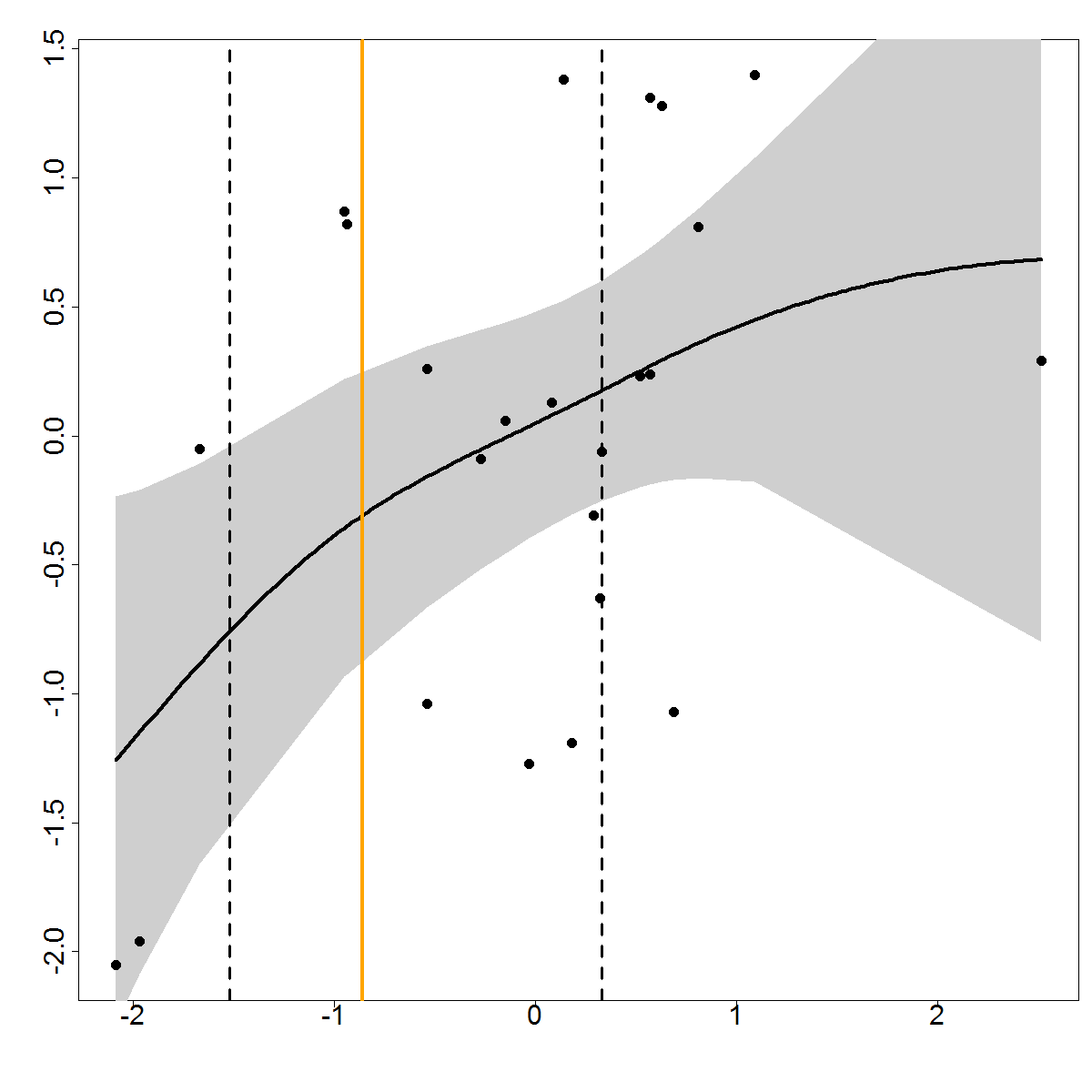
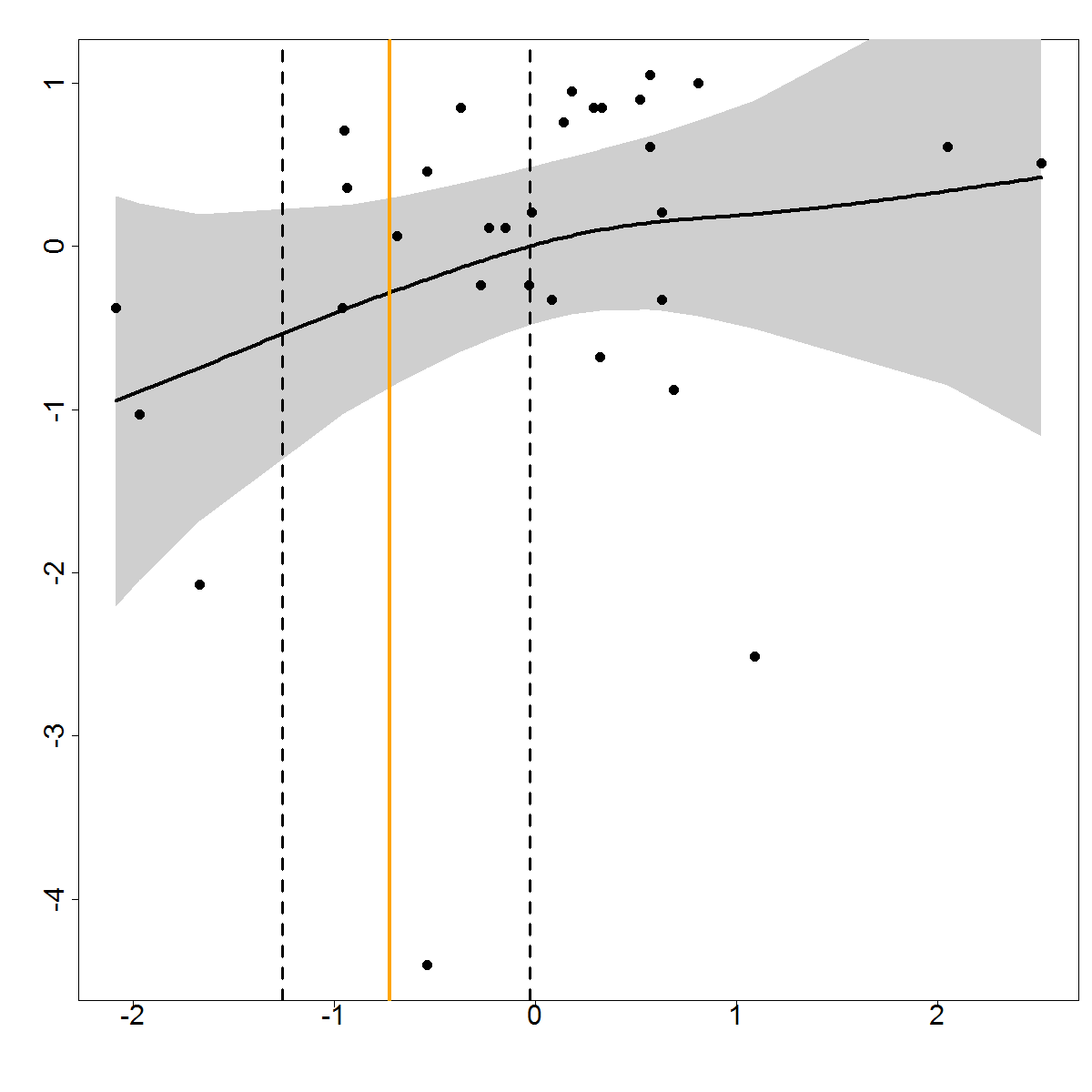
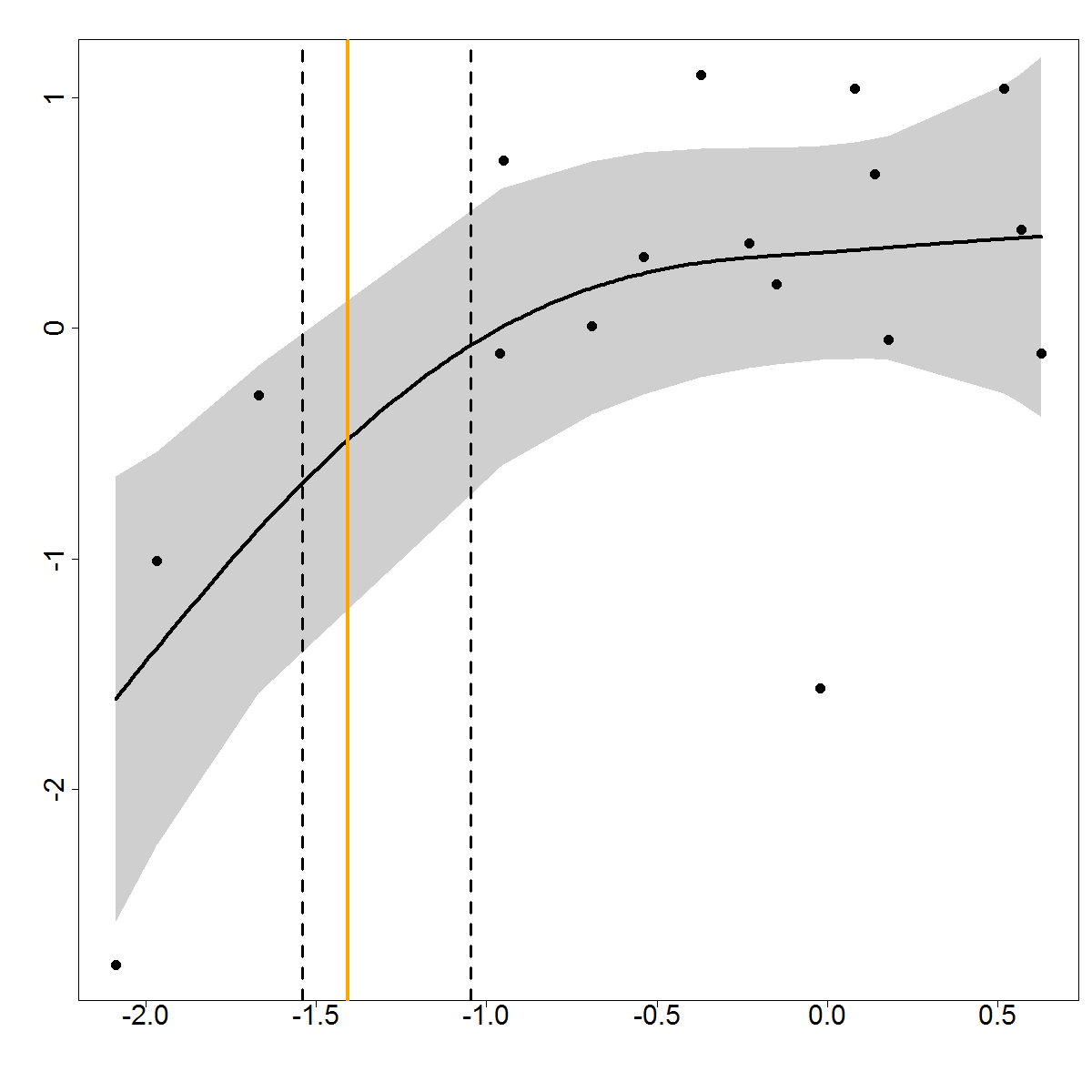
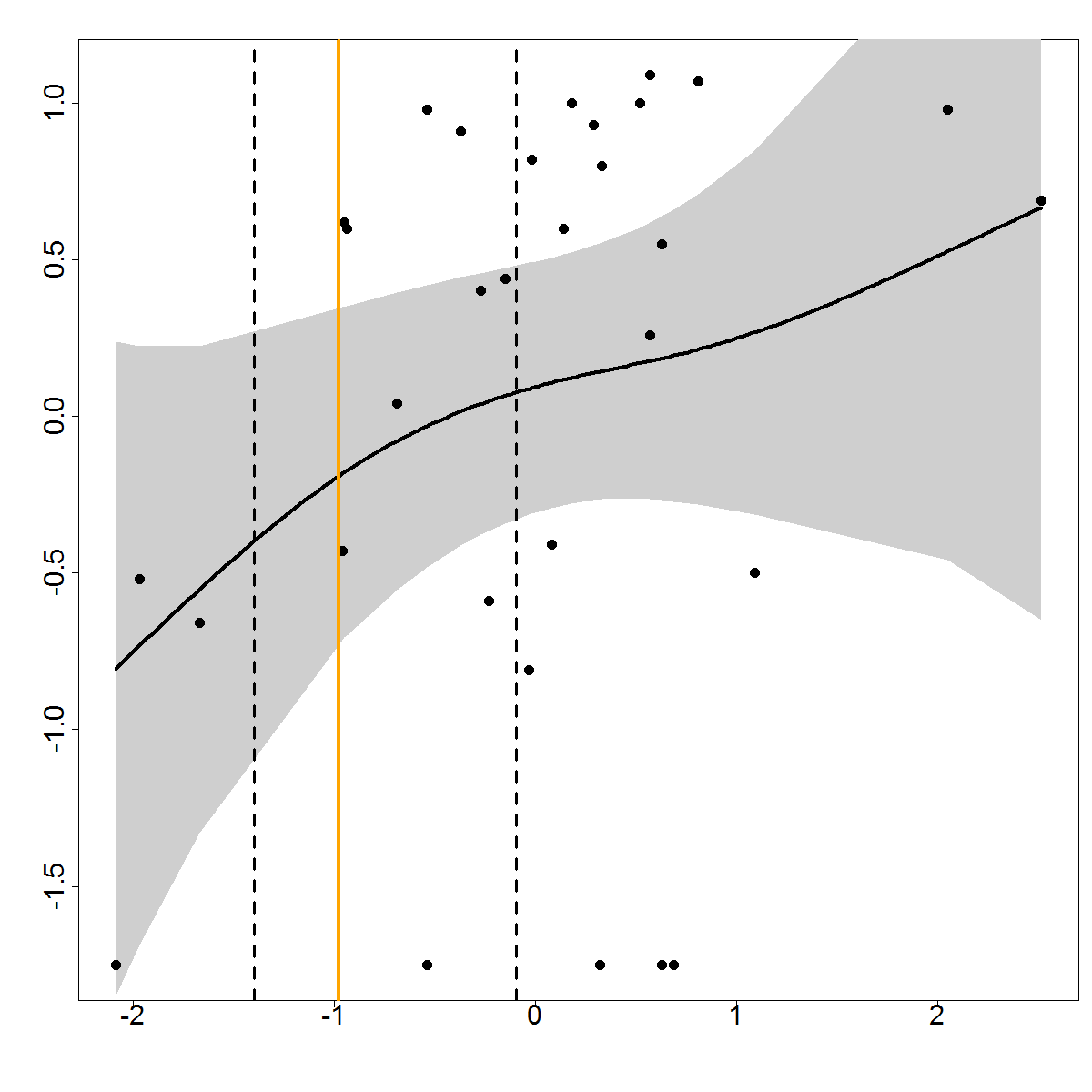
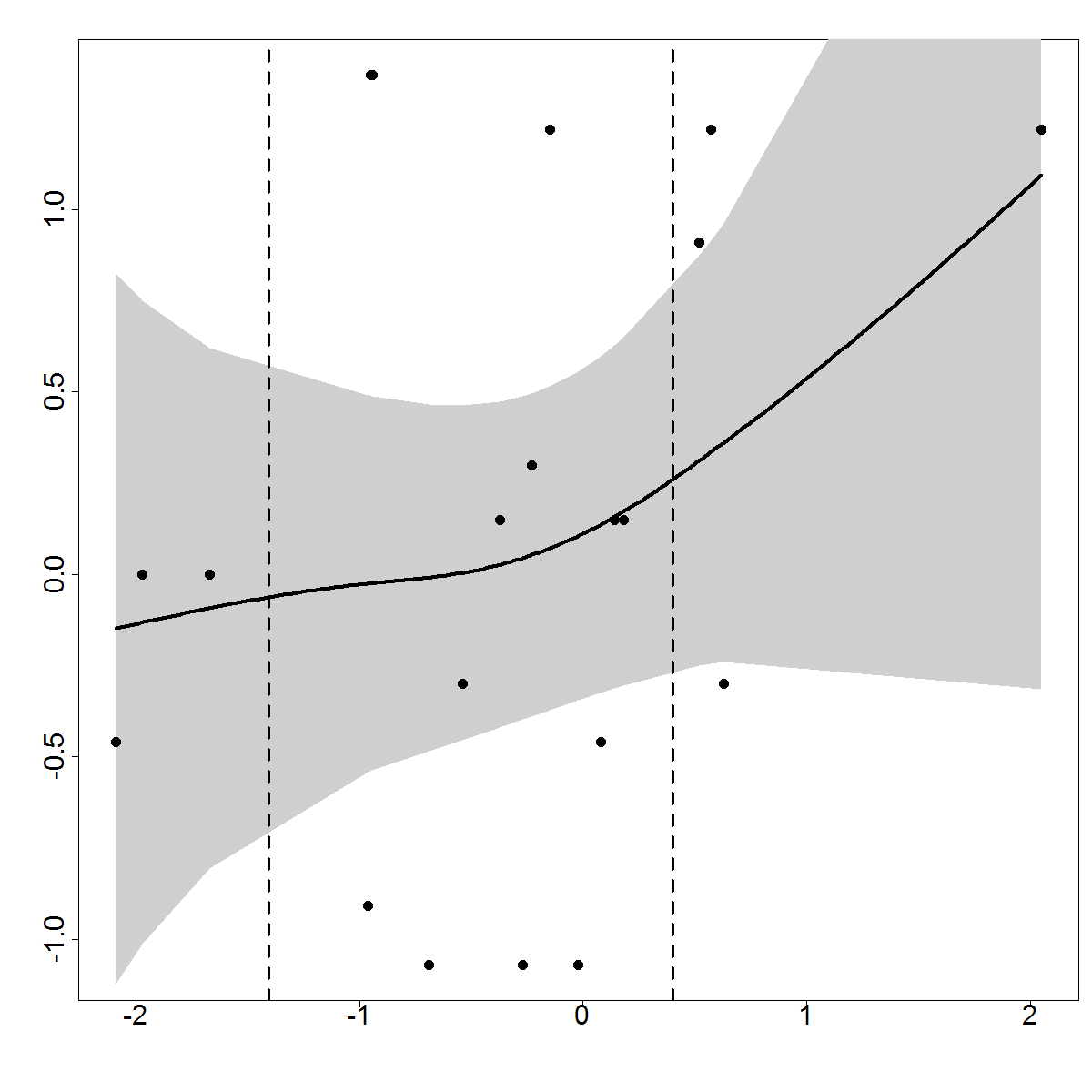
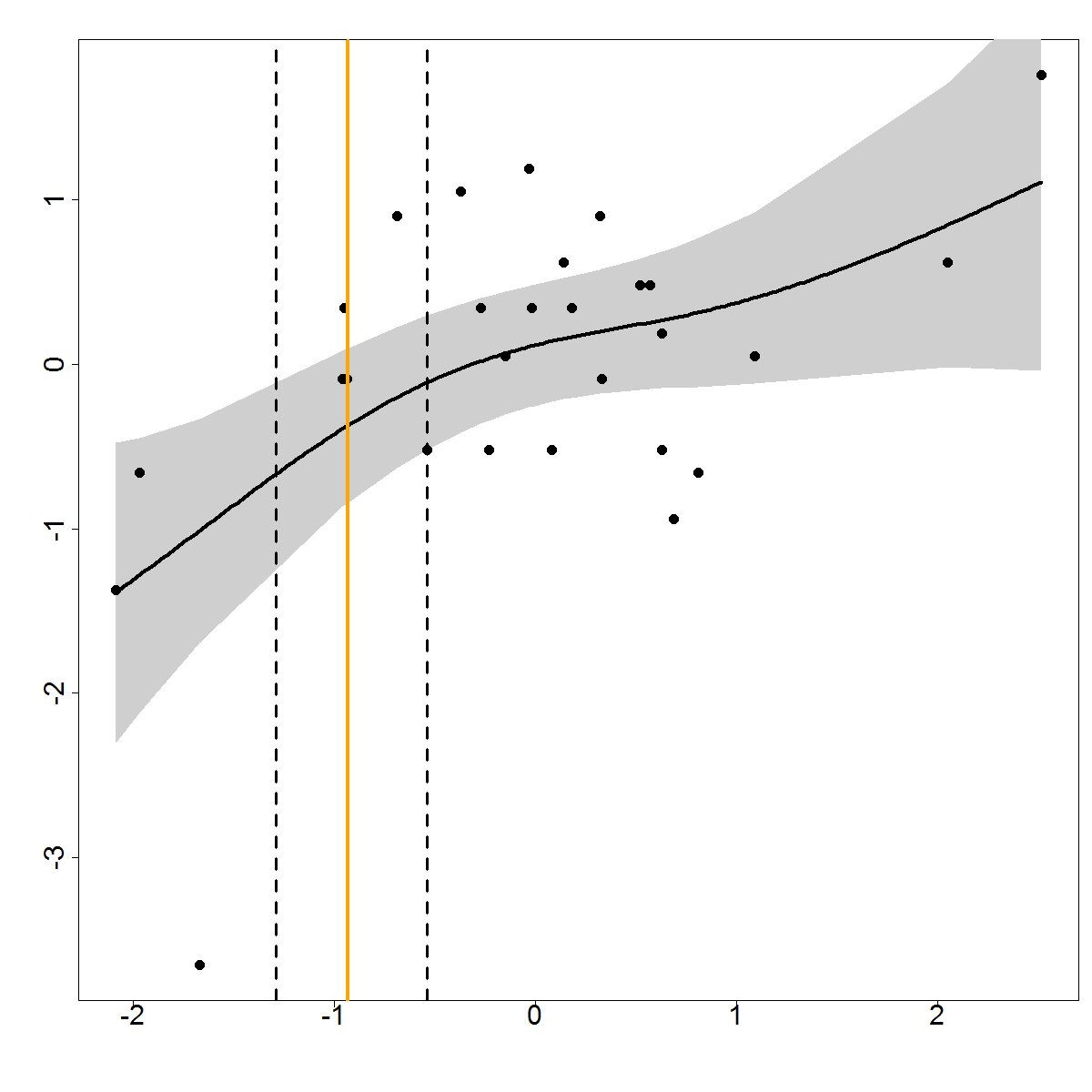
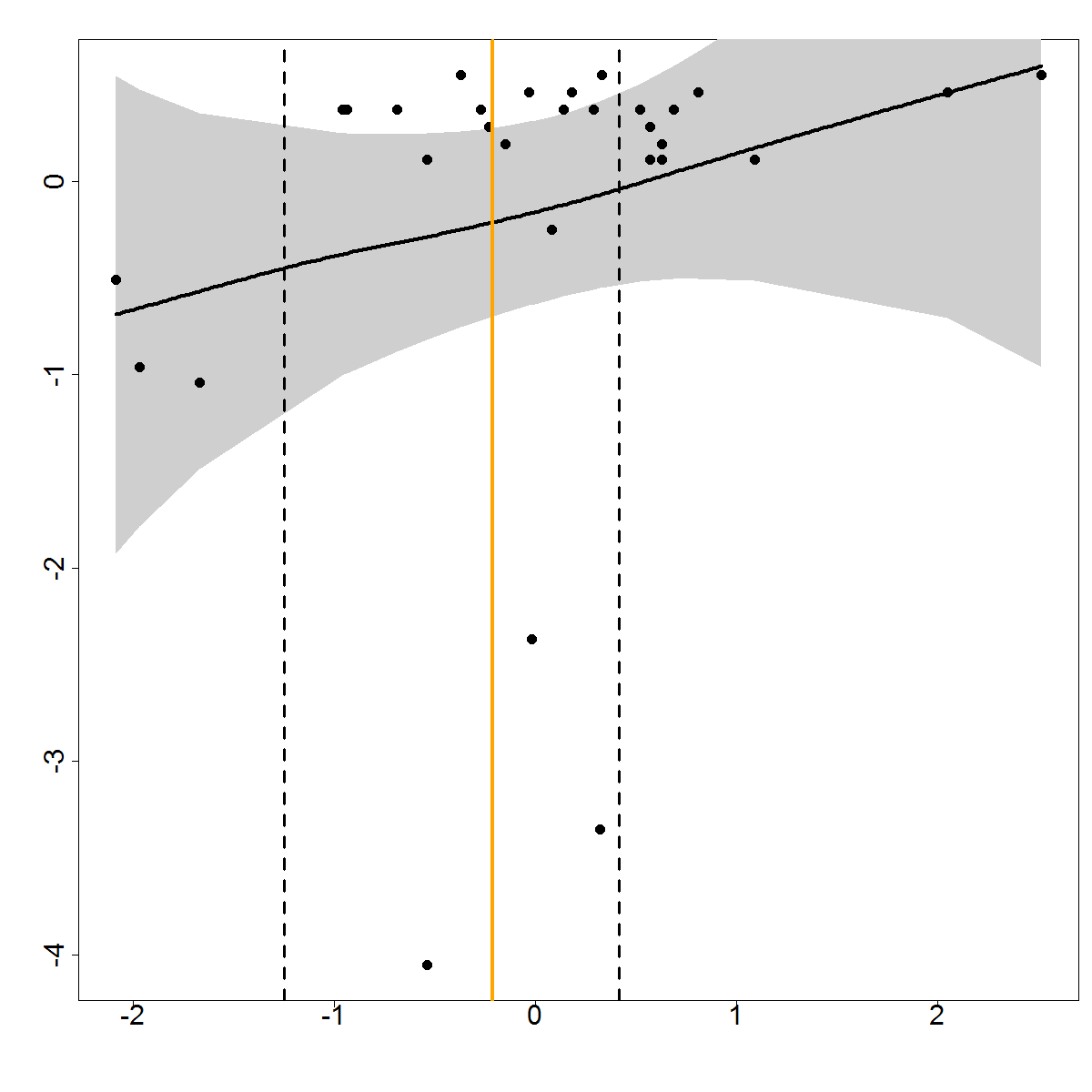
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**II**

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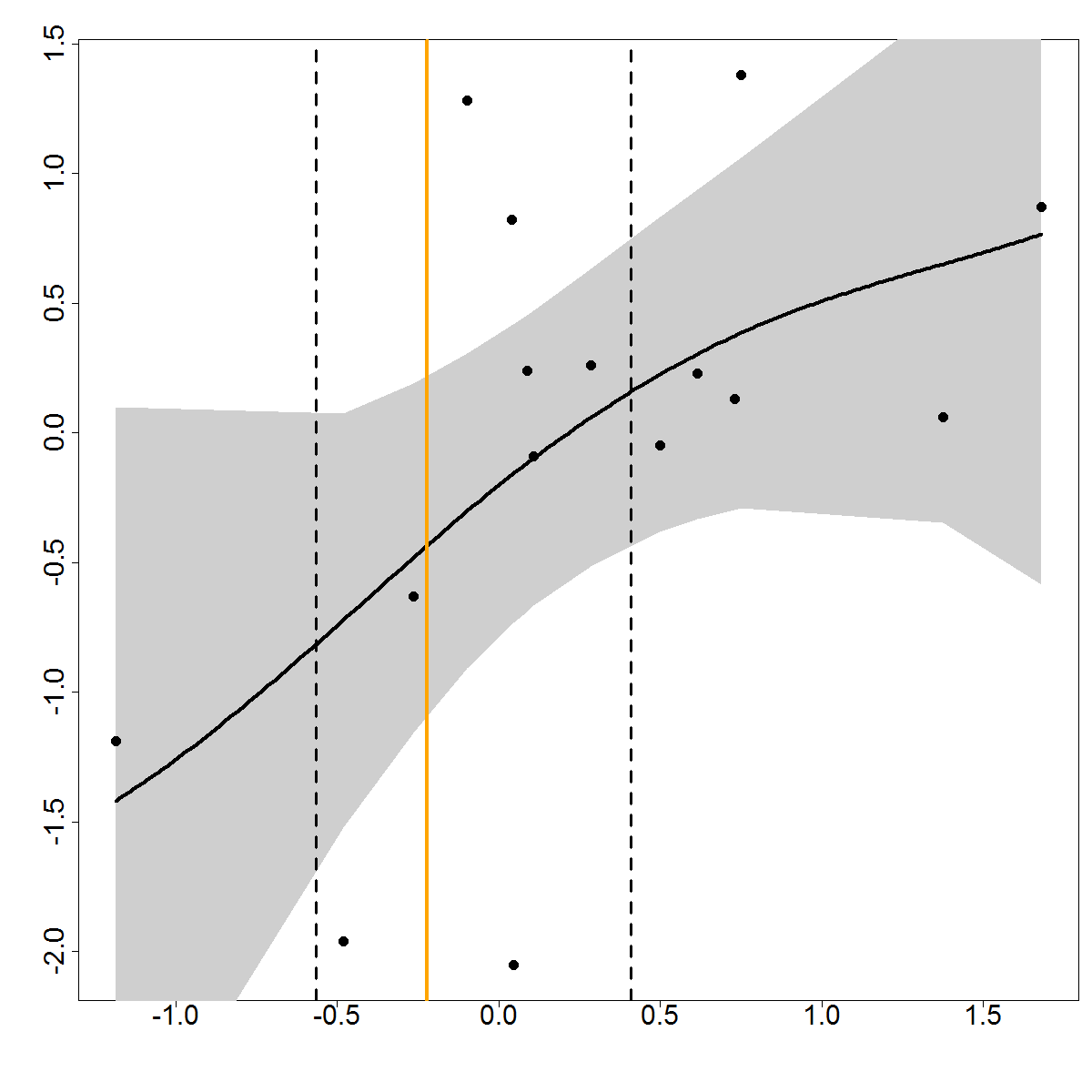
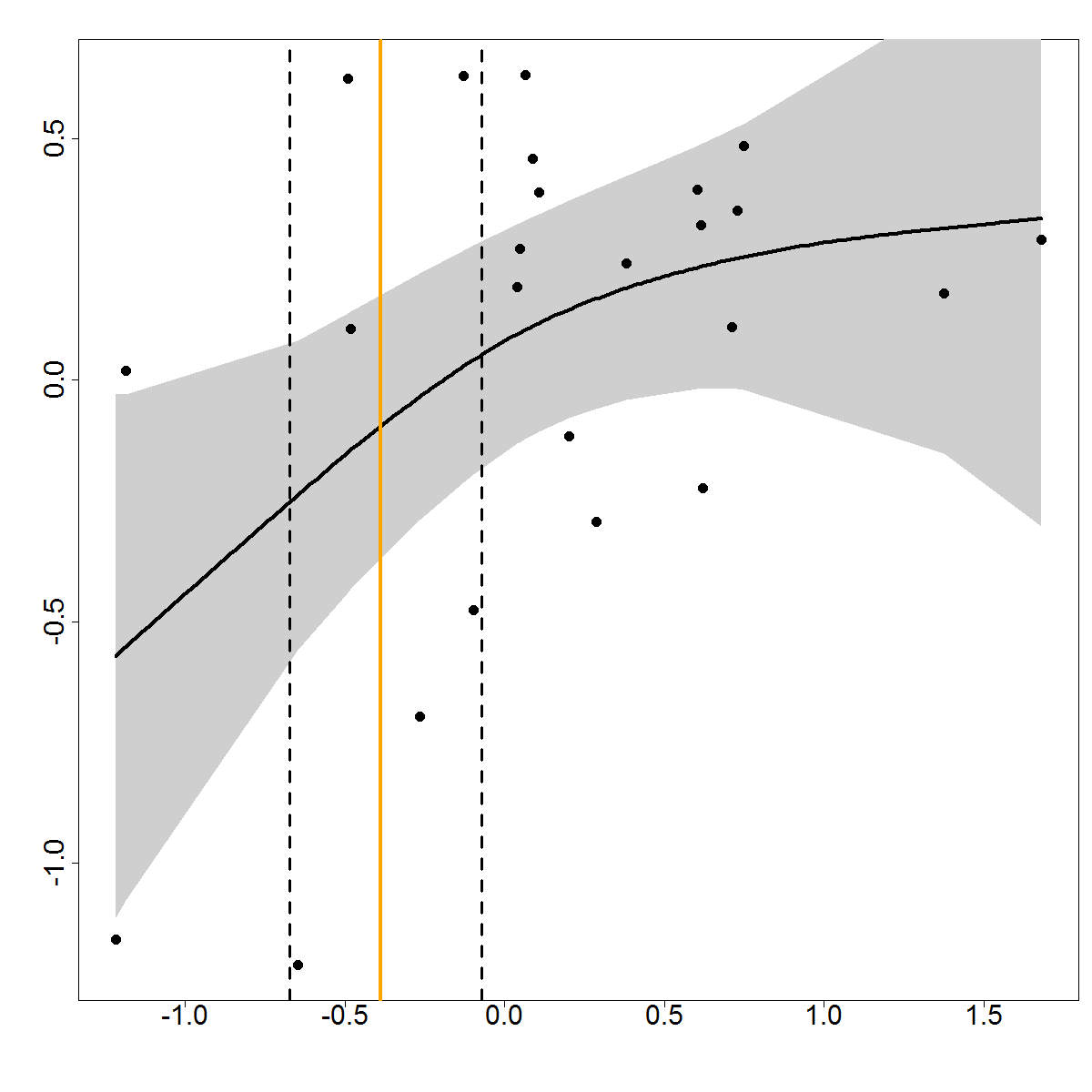
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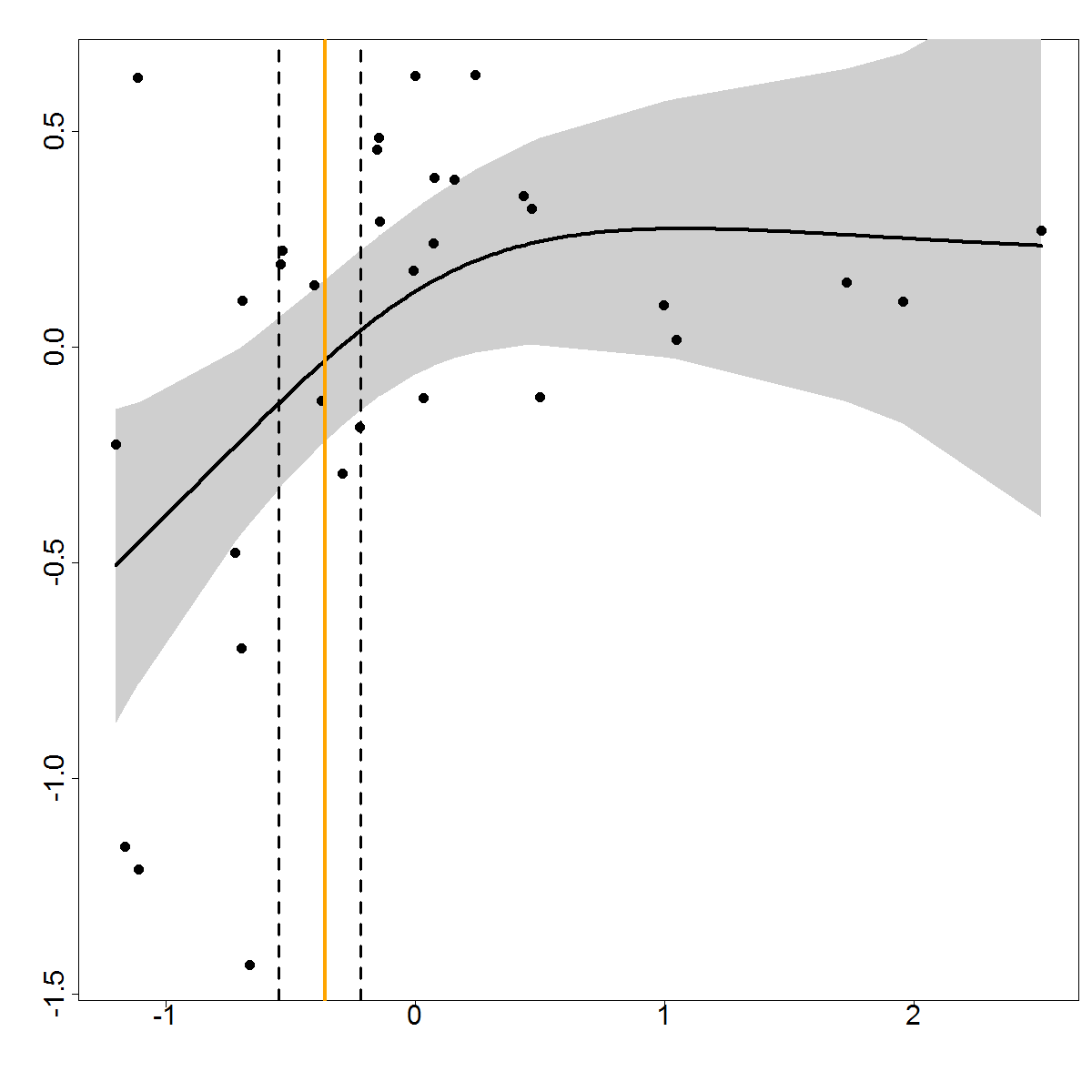
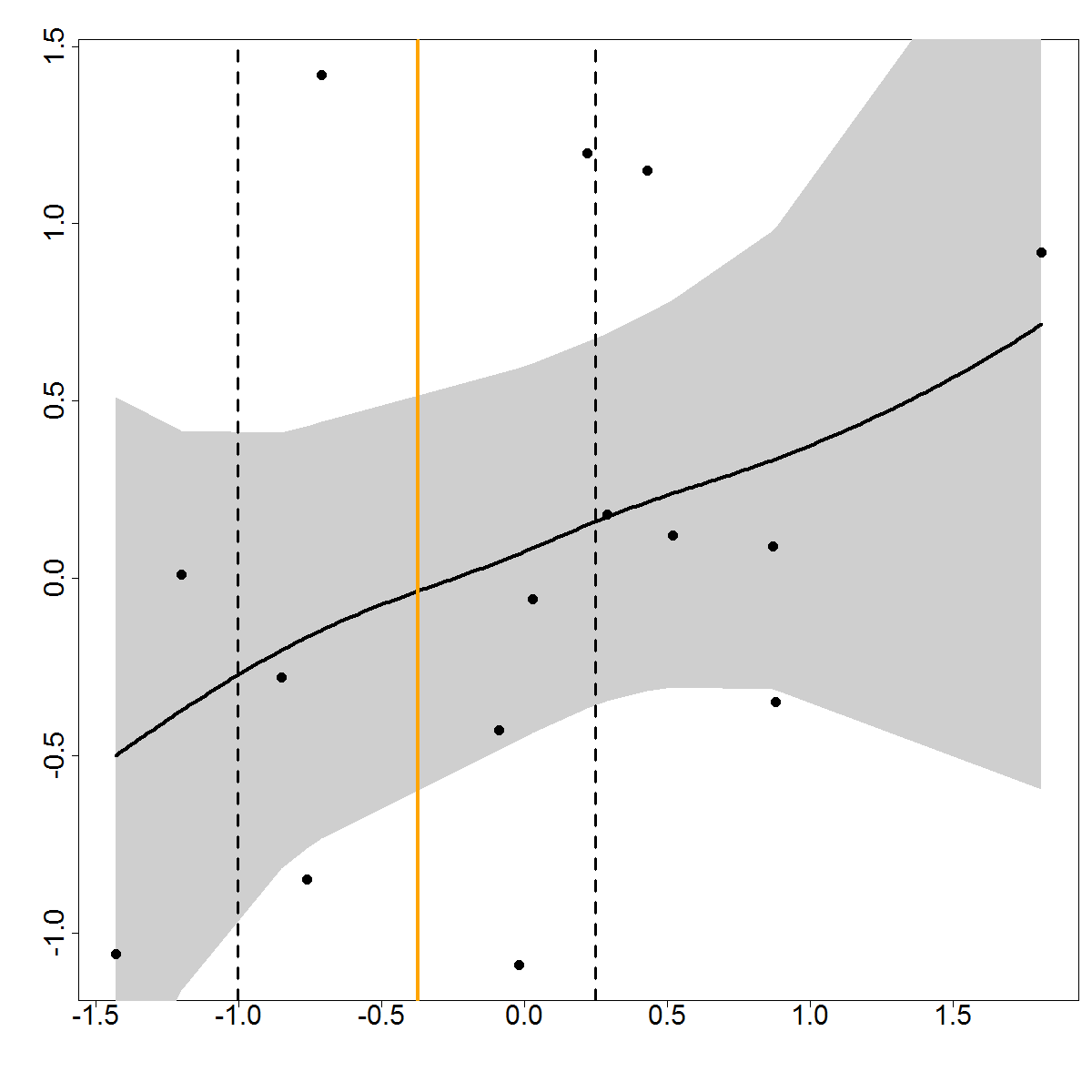
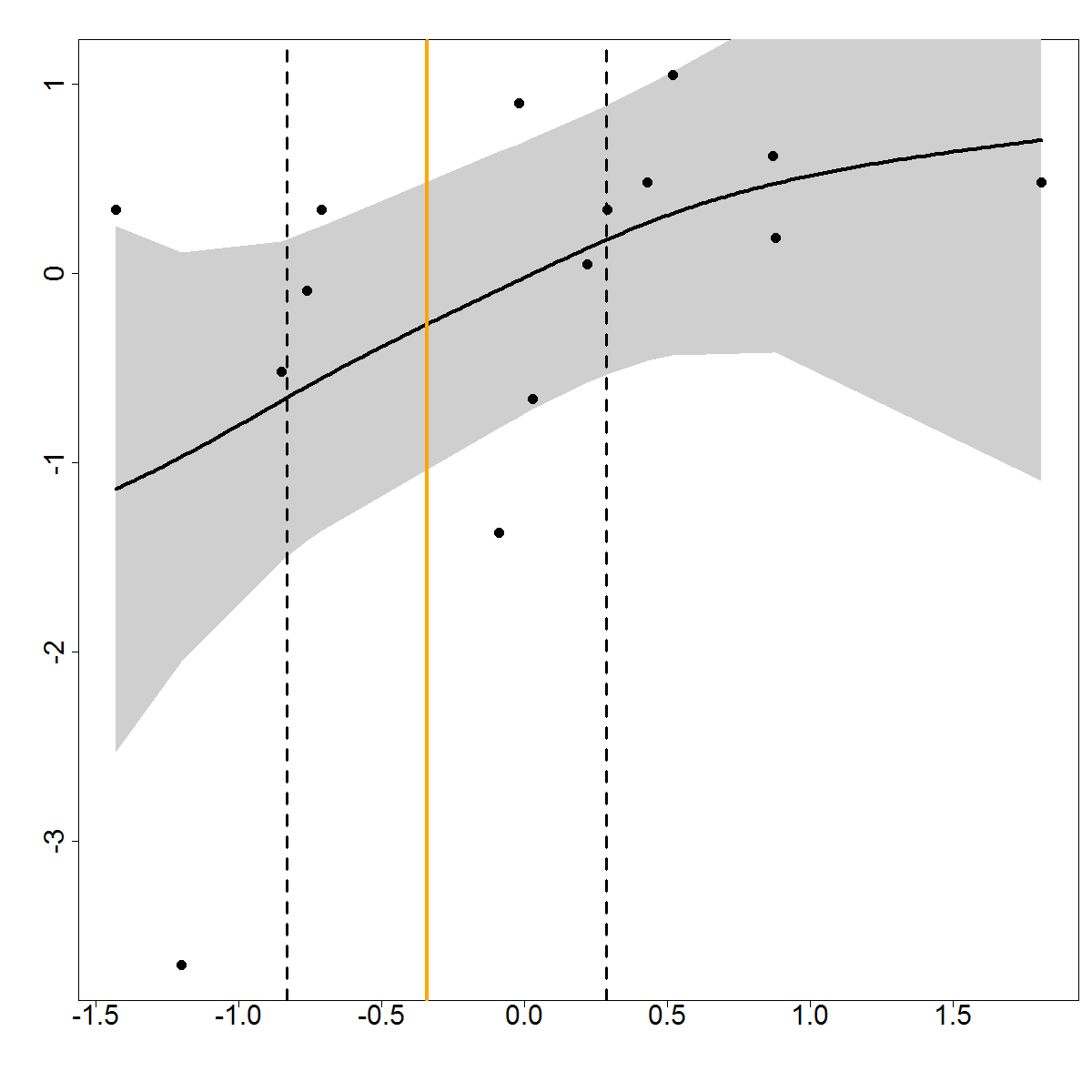
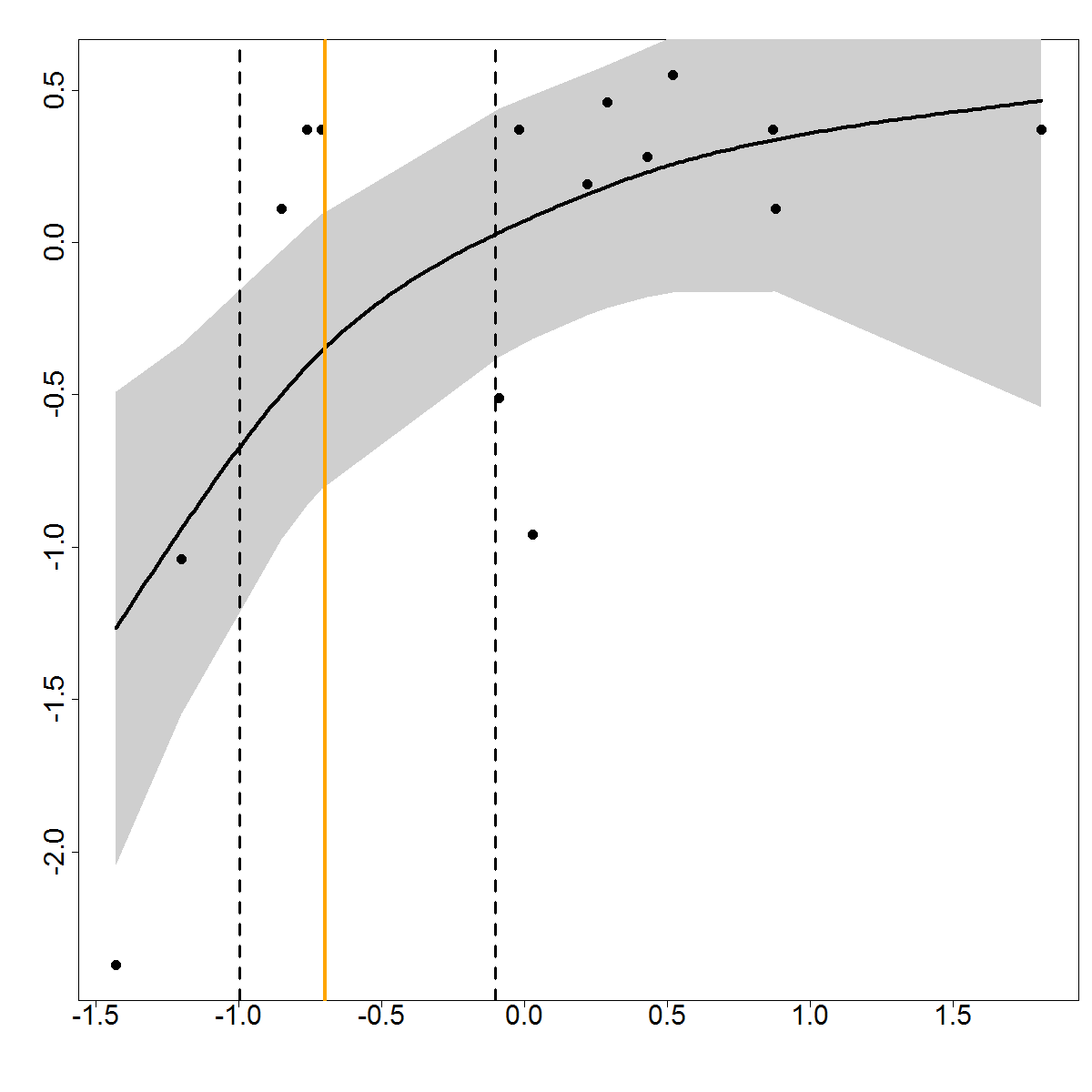
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**III**

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**IV**

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**Supplemental Material II**

***Northern CCE*.** Appropriate overlap of predator-prey time series was largely lacking for the northern CCE. Cury et al*.* (2011) suggested that at least 13 years of predator-prey data were needed to demonstrate prey thresholds and 11 years of data to determine prey maxima; our study also found no good models with less than 11 years of data. For example, common murre reproductive success at Yaquina Head, Oregon (Gladics et al*.* 2012, Leising et al*.* 2014), and growth indices for three rockfish species derived from otolith rings in northern California and Oregon (Black et al*.* 2005, 2008) were examined but yielded no good threshold models due to the low number of years corresponding to indices of prey (NMFS forage fish surveys off Oregon (R. Emmett and R. Brodeur/NOAA; Emmett and Brodeur 2000, Emmett et al*.* 2005, Brodeur et al*.* 2006, Leising et al*.* 2014).

Available pinniped datasets in this region did not distinguish measures of productivity (e.g., pup counts) and thus could not be used (Jeffries et al. 2003, Brown et al*.* 2005, Lowry et al*.* 2008). Many predatory fish time series off the Oregon and/or Washington coasts included predators of copepods, which did not fit our criteria for mid-trophic forage species (see Szoboszlai et al*.* 2015), and krill, for which we also did not have abundance indices in this region.

We did find relationships of Chinook salmon survival in the northern CCE with anchovy and whitebait smelt (*Allosmerus elongatus*) (threshold -0.24 normalized anchovy value and 54% of maximum anchovy index value; and -0.65 and 48%, respectively, for whitebait smelt), although these models were not very robust with only 11 years of data each. The relatively high thresholds may be a result of poor sample size, or indicate use of alternate prey; indeed, we know that Chinook salmon diet in that region can be quite diverse (Daly et al*.* 2009). Future work includes testing our hypothesis in the northern CCE when both predator and prey time series have accrued additional years of data.

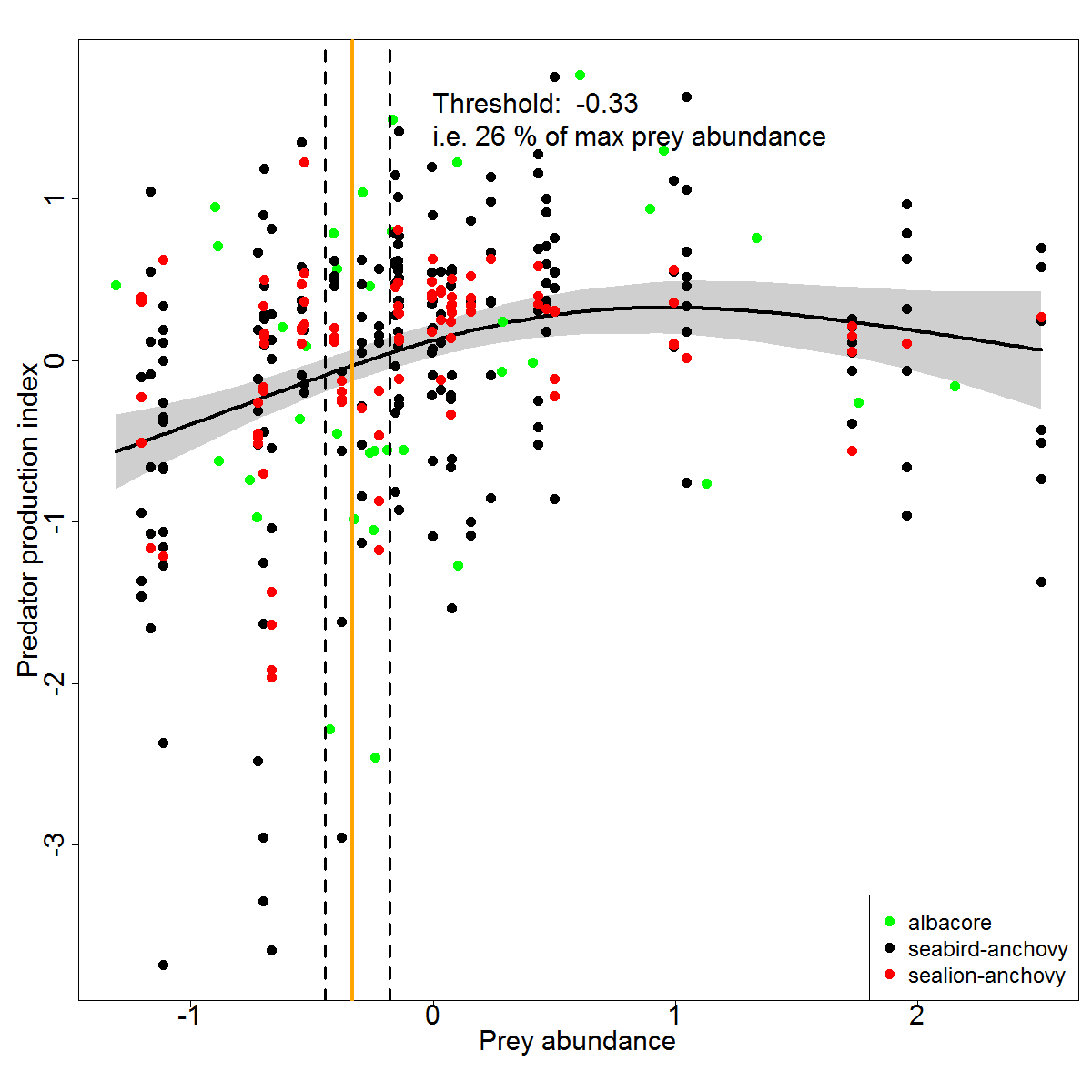
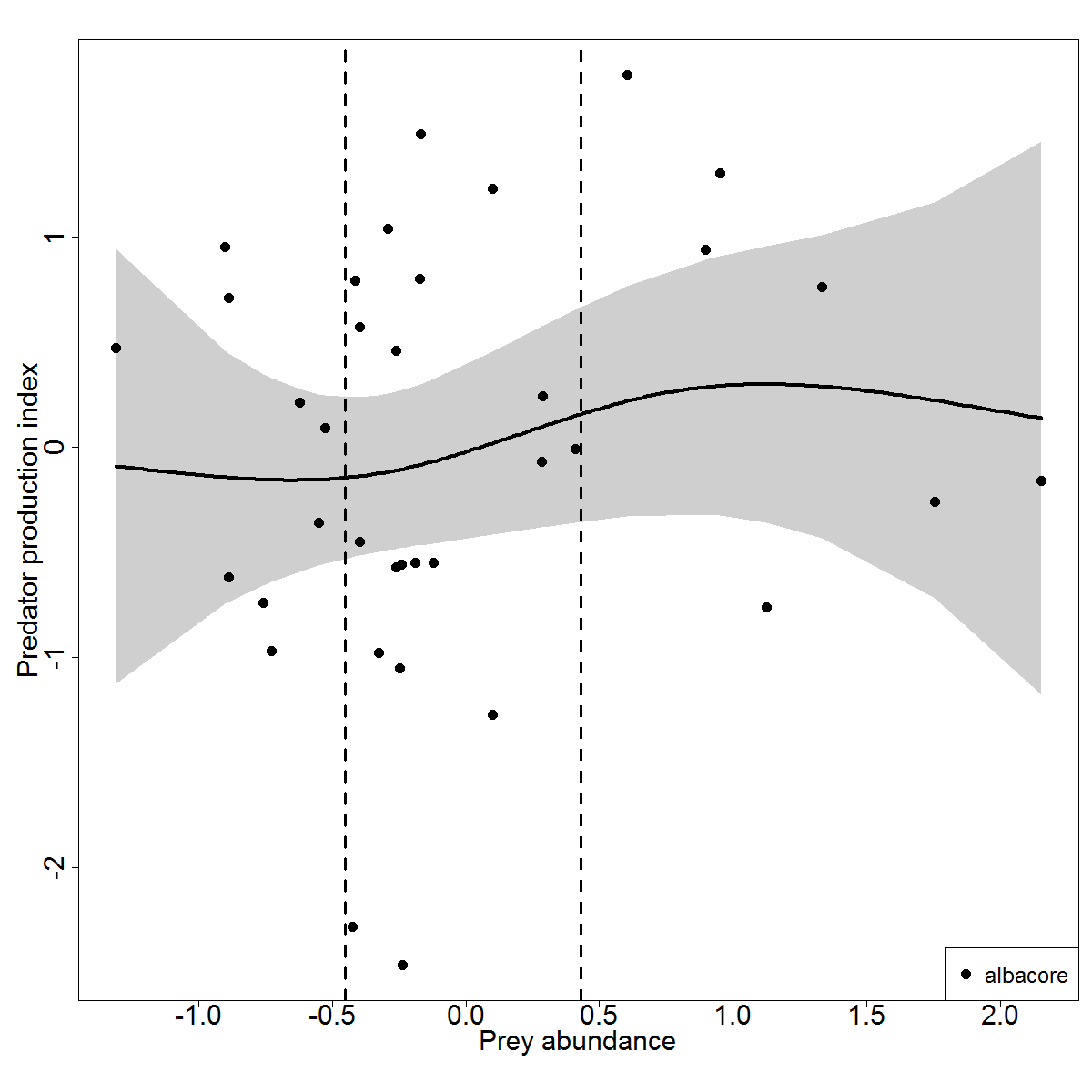
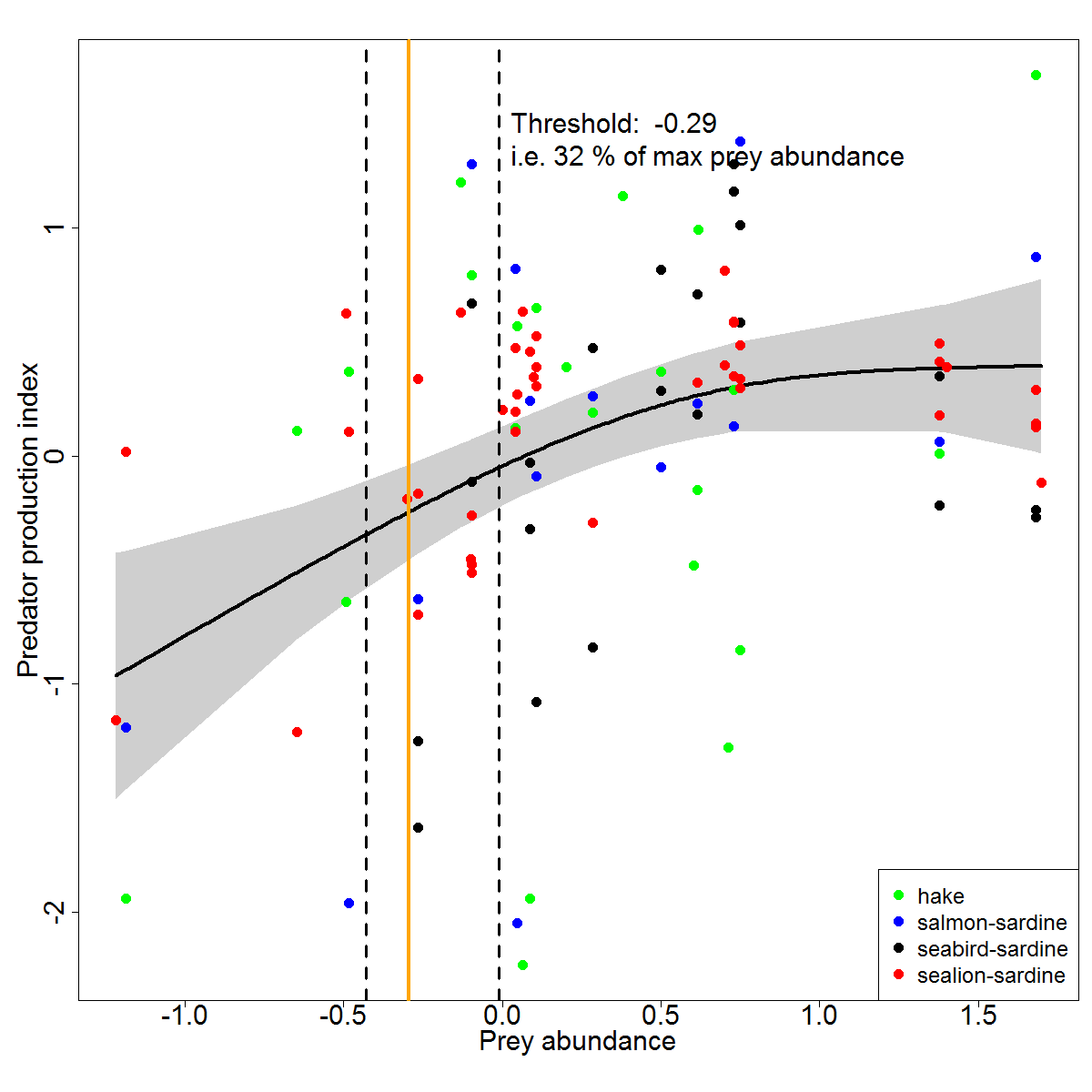
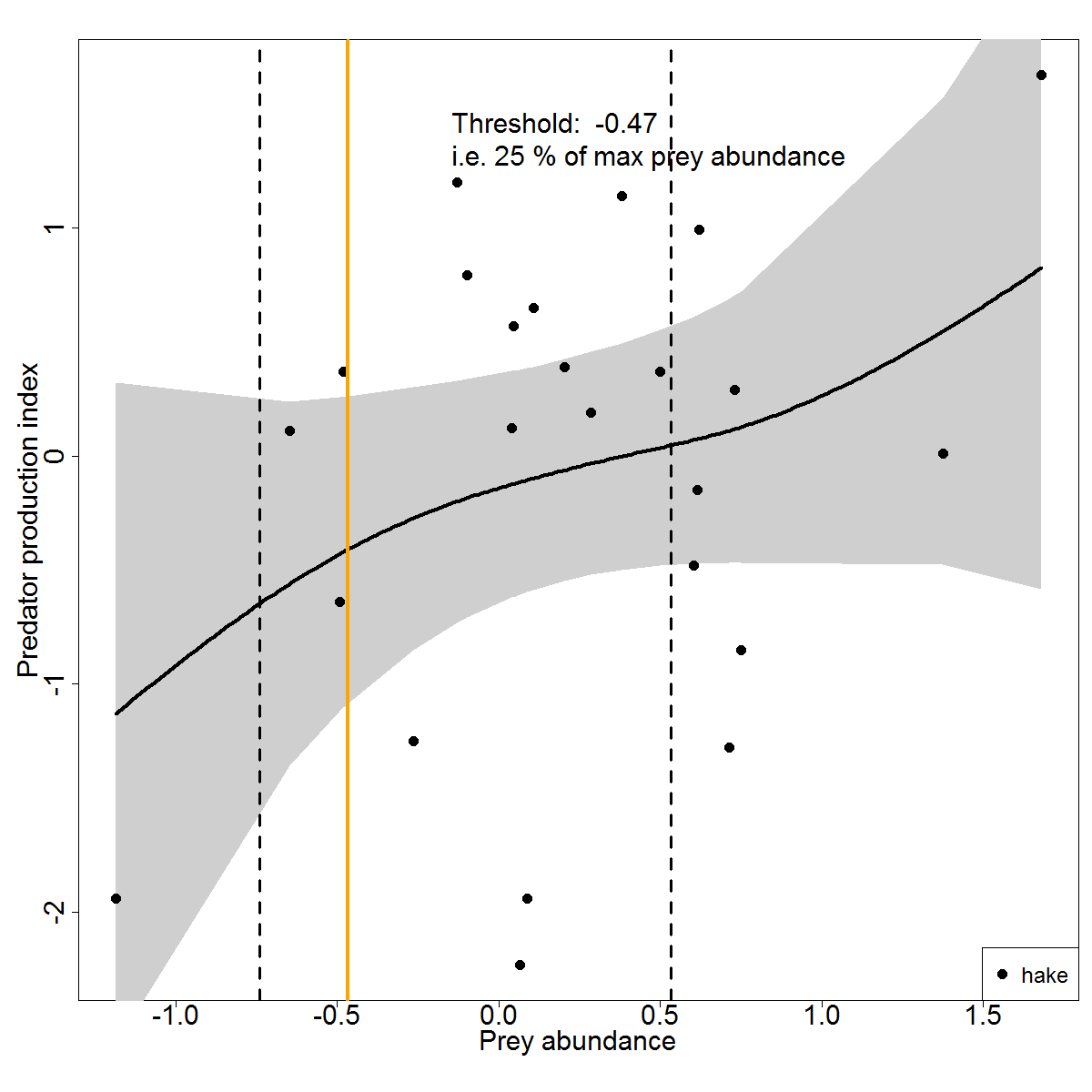
***Modeled predatory fish indices*.** Recruitment data for several iteroparous commercial fish species was obtained from stock assessments, which were modeled rather than observed data. Therefore, these were not included in our main analysis, although results here did support our conclusions. The stock assessments were conducted at the federal level of management and thus not partitioned into regions within the CCE; rather, these data spanned the entire west coast of the U.S. Hake recruitment was modeled against sardine prey, yielding a somewhat lower threshold than was observed for other sardine predators, although similar to overall thresholds observed in the CCE (Table S3; Fig. S2a,b). Albacore recruitment was compared against anchovy prey. While separate models did not converge to yield thresholds (Table S3; Figure S2c), approximate confidence intervals around the change points of each function were similar to those of marine birds and mammals that exhibited clear relationships with anchovy (lower 22% to upper 50% for albacore; 17 – 34% for marine birds and mammals). The lack of a clear single-prey threshold here was likely influenced by alternate prey usage in this highly migratory predator. Additionally, Glaser et al. (2015) suggested that the northern CCS is a more significant source of prey for albacore, while we modeled prey in the central to southern CCS in this study.

**Table S3.** Prey thresholds of predatory fish recruitment versus overall predator thresholds including productivity of all other predators. *Predator indices: Observed reproductive success or young fledged per breeding pair = RS, Peak pup count = Pup, Survival of ocean period salmon = Returns; Modeled recruitment = Recruit. See text for location definitions.*

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Predator** | **Prey** | **Region** | **Specific location** | **Predator index** | **N pred. spp.** | **N colonies/ subpops** | **Prey threshold** | **Years modeled** | **N spp -yrs** | |
| Hake | Sardine | U.S. west coast | CA, OR, WA | Recruit | 1 | 1 | (-0.54) **23%** | 1992-2011 | | 24 |
| Seabird, sea lion, fish (incl. hake) | Sardine | central CA | SBI, ANA, SMI, SCI, SNI, CV, coastal | RS, Pup, Survival, Recruit | 4 | 8 | (-0.28) **32%** | 1992-2011 | | 103 |
| Albacore | Anchovy | U.S. west coast | CA, OR, WA | Recruit | 1 | 1 | no threshold\* | 1966-2011 | | 36 |
| Seabird, sea lion, fish (incl. albacore) | Anchovy | CA | SFI, ANI, ALZ, SBI, ANA, VB, SMI, SCI, SNI, coastal | RS, Pup, Recruit | 7 | 10 | (-0.33) **27%** | 1966-2011 | | 328 |

*\* Where there were sufficient observations but the model did not converge to calculate a threshold, data in the upper left quadrant of curve, when prey abundance was high yet predator productivity was low, signaled alternate prey use precluding a significant relationship with just one prey species.*

**Figure S2**. Models of predatory fish indices of recruitment against forage species: a) U.S. West Coast hake and sardine prey and b) CCE predators on sardine, including hake; c) U.S. West Coast albacore and anchovy prey and d) CCE predators on anchovy, including albacore.



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