Trophic Ecology of nine top predators in the California Current

by
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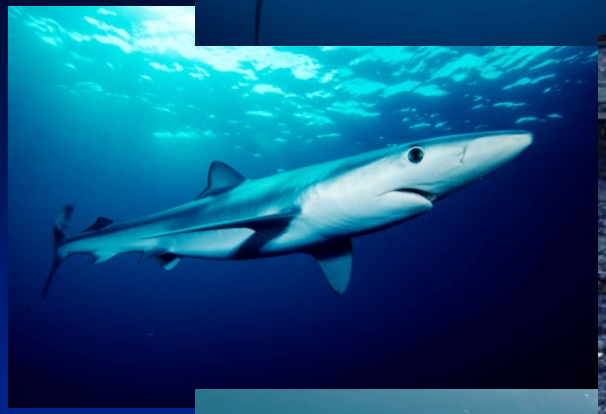
Short-beaked common dolphin
Delphinus delphis



Long-beaked common dolphin
Delphinus capensis

Northern Right Whale Dolphin
Lissodelphis borealis

Pacific White-Sided Dolphin
Lagenorhyncus borealis

Project overview

- Diets of sharks and swordfish
- Interspecific diet comparisons
- Diets of cetaceans
- Trophic ecology, stable isotope analysis (sharks and swordfish)
- Parasites analysis, ‘biological tagging’ (spiral valve contents, thresher and blue)

The sample

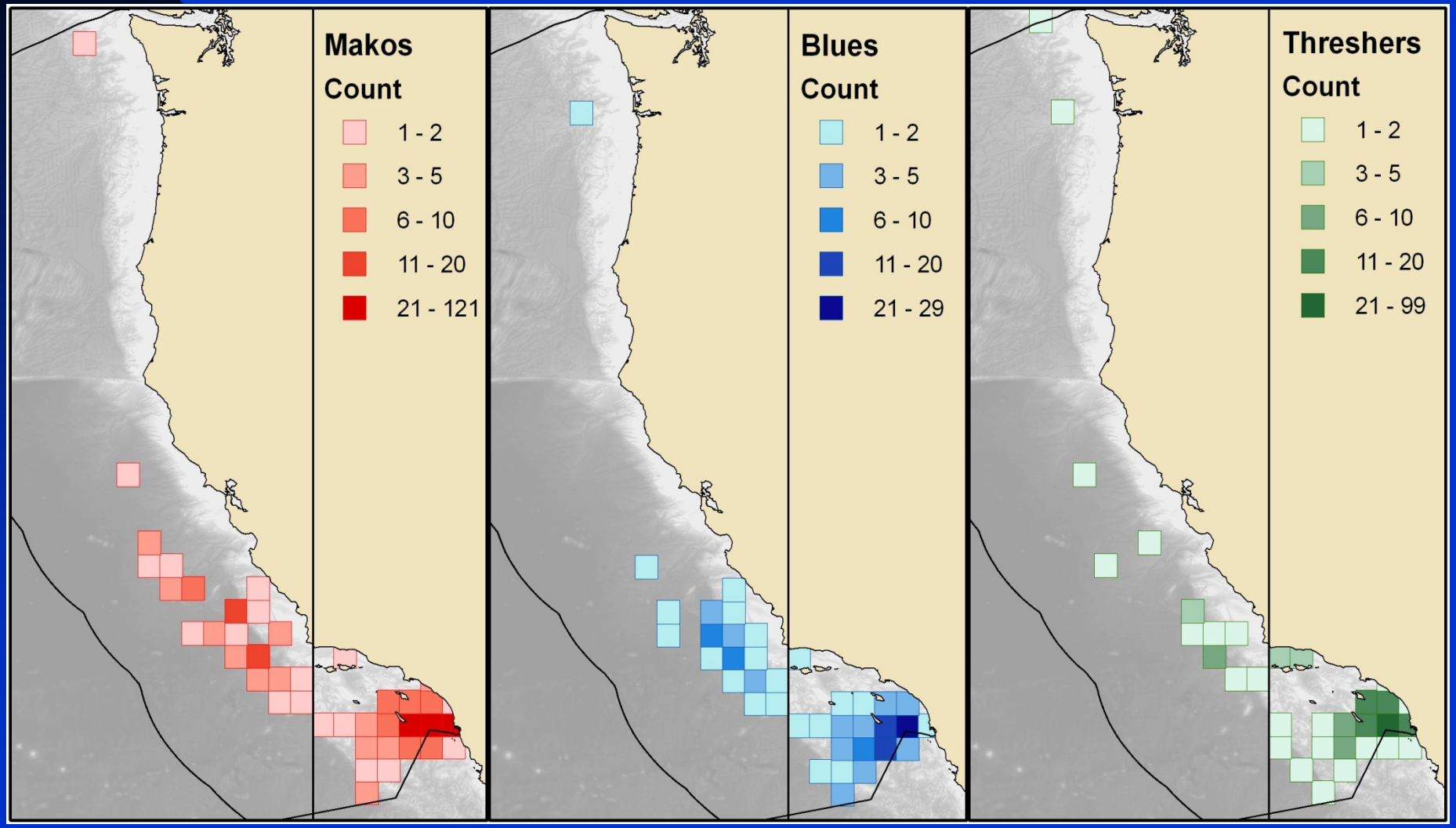
Over 2000 stomachs analyzed:

- **sharks / swordfish: California drift gillnet (CADGN)**
- **cetaceans: CADGN and strandings**

Cetaceans :

- **the historical SWFSC stomach content collection pre-sorted in vials (mostly hard parts)**
- **stomach dissections for the recent years**

Sample collections East/West 120º30'W



Time series : stomach samples (fish)

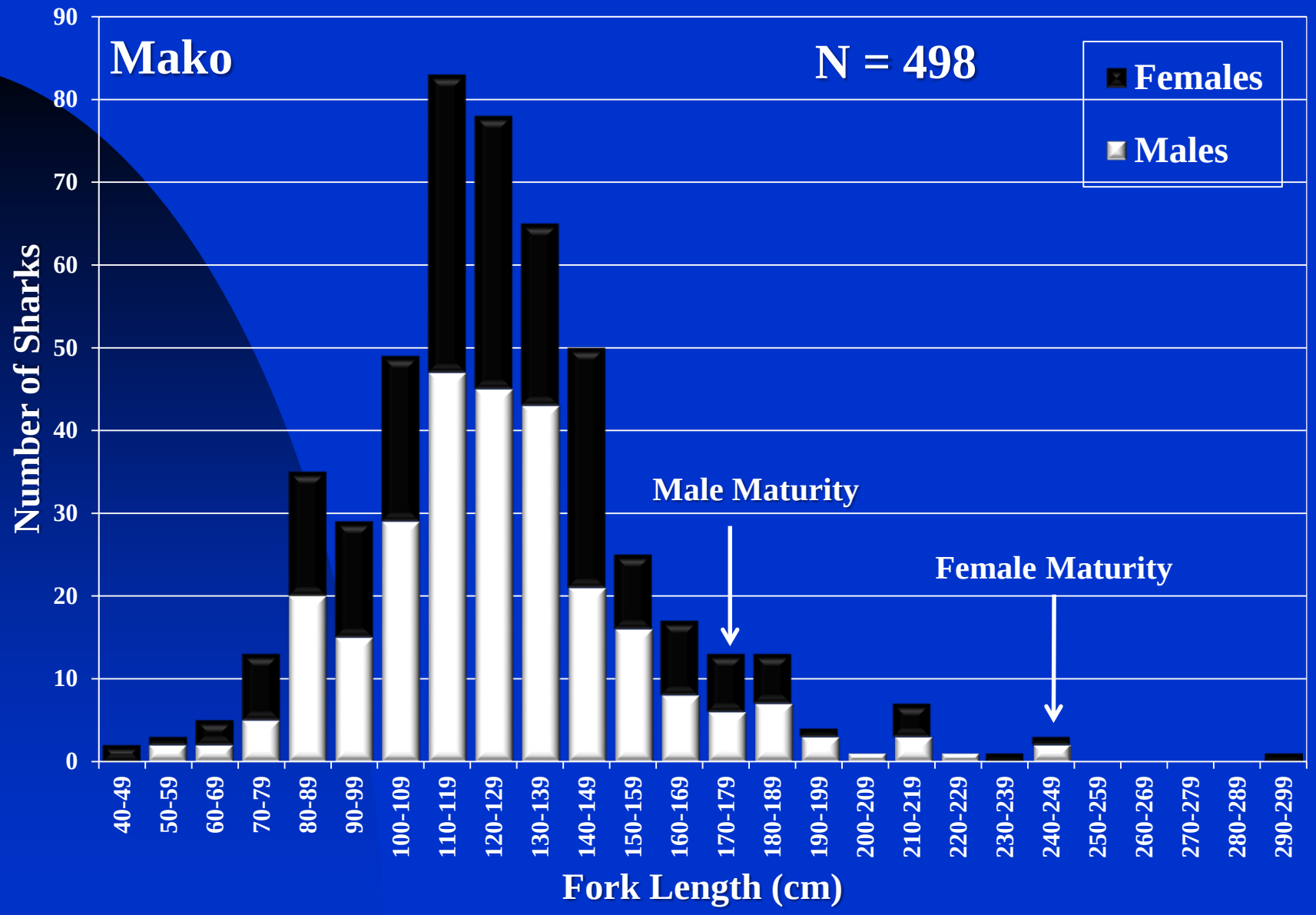
Shortfin mako: 2002-14

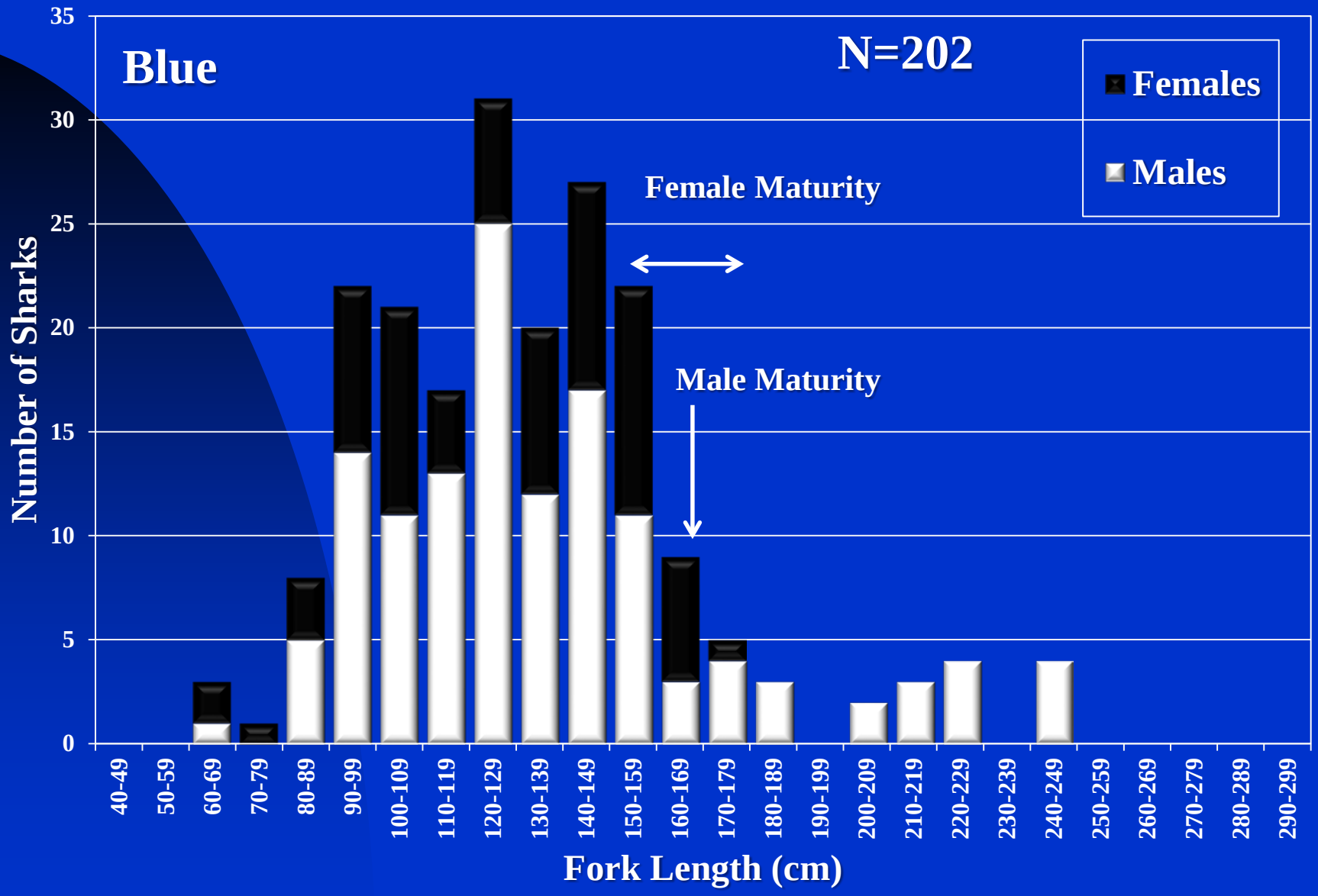
Blue shark: 2002-14

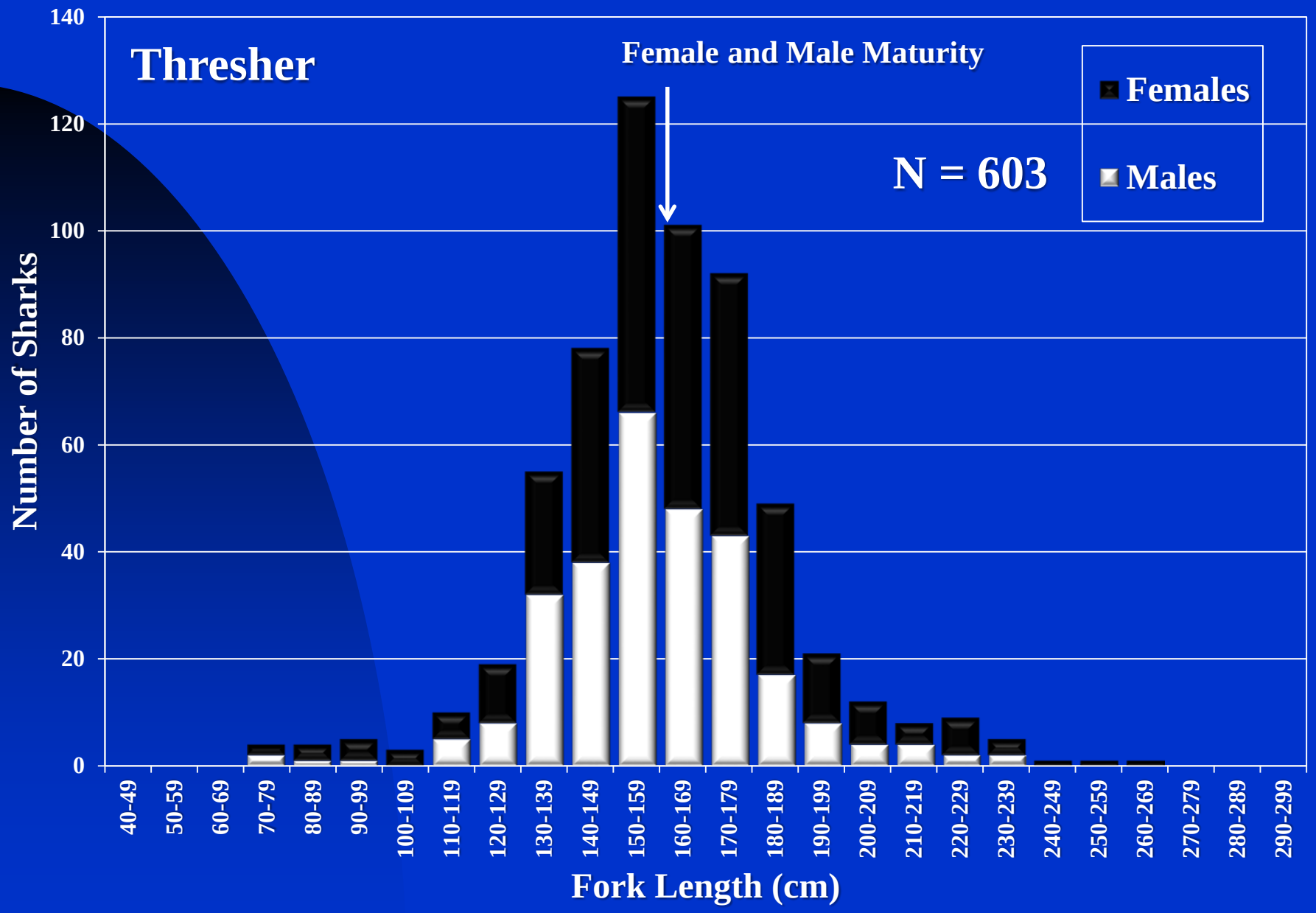
Thresher shark: 1998-00 and 2002-14

Bigeye thresher shark: 1998-99; 2002-10; 2014 (few samples)

Broadbill swordfish: 2007-14


Mako
N = 498
Females
Males
Number of Sharks
0
10
20
30
40
50
60
70
80
90
Male Maturity
Female Maturity
40-49
50-59
60-69
70-79
80-89
90-99
100-109
110-119
120-129
130-139
140-149
150-159
160-169
170-179
180-189
190-199
200-209
210-219
220-229
230-239
240-249
250-259
260-269
270-279
280-289
290-299
Fork Length (cm)


Blue
N=202
Females
Males
Female Maturity
Male Maturity
Number of Sharks
35
30
25
20
15
10
5
0
40-49
50-59
60-69
70-79
80-89
90-99
100-109
110-119
120-129
130-139
140-149
150-159
160-169
170-179
180-189
190-199
200-209
210-219
220-229
230-239
240-249
250-259
260-269
270-279
280-289
290-299
Fork Length (cm)


Thresher
Female and Male Maturity
Females
Males
N = 603
Number of Sharks
0
20
40
60
80
100
120
140
40-49
50-59
60-69
70-79
80-89
90-99
100-109
110-119
120-129
130-139
140-149
150-159
160-169
170-179
180-189
190-199
200-209
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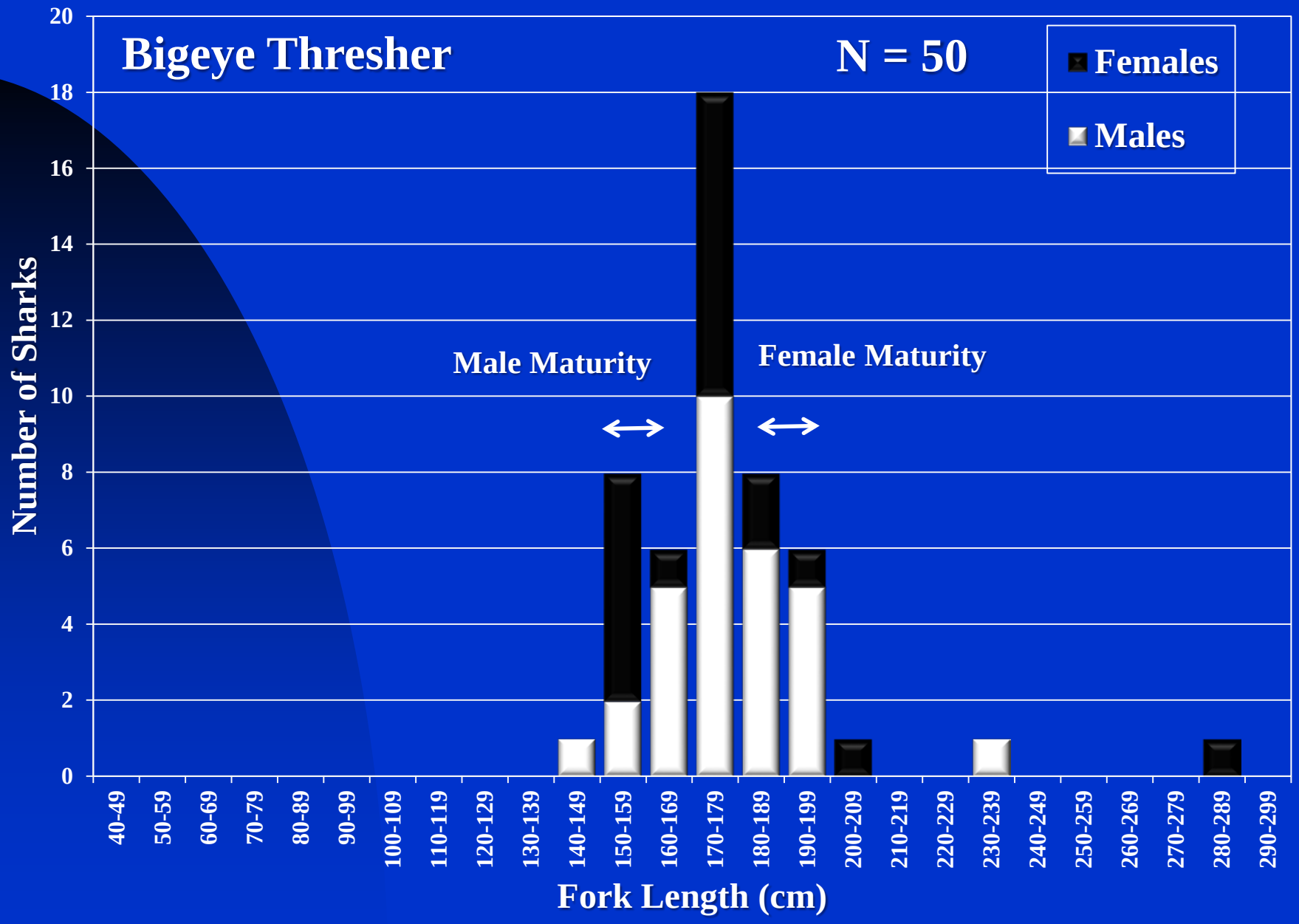
220-229
230-239
240-249
250-259
260-269
270-279
280-289
290-299
Fork Length (cm)


Bigeye Thresher
N = 50
Females
Males
Male Maturity
Female Maturity
Number of Sharks
0
2
4
6
8
10
12
14
16
18
20
40-49
50-59
60-69
70-79
80-89
90-99
100-109
110-119
120-129
130-139
140-149
150-159
160-169
170-179
180-189
190-199
200-209
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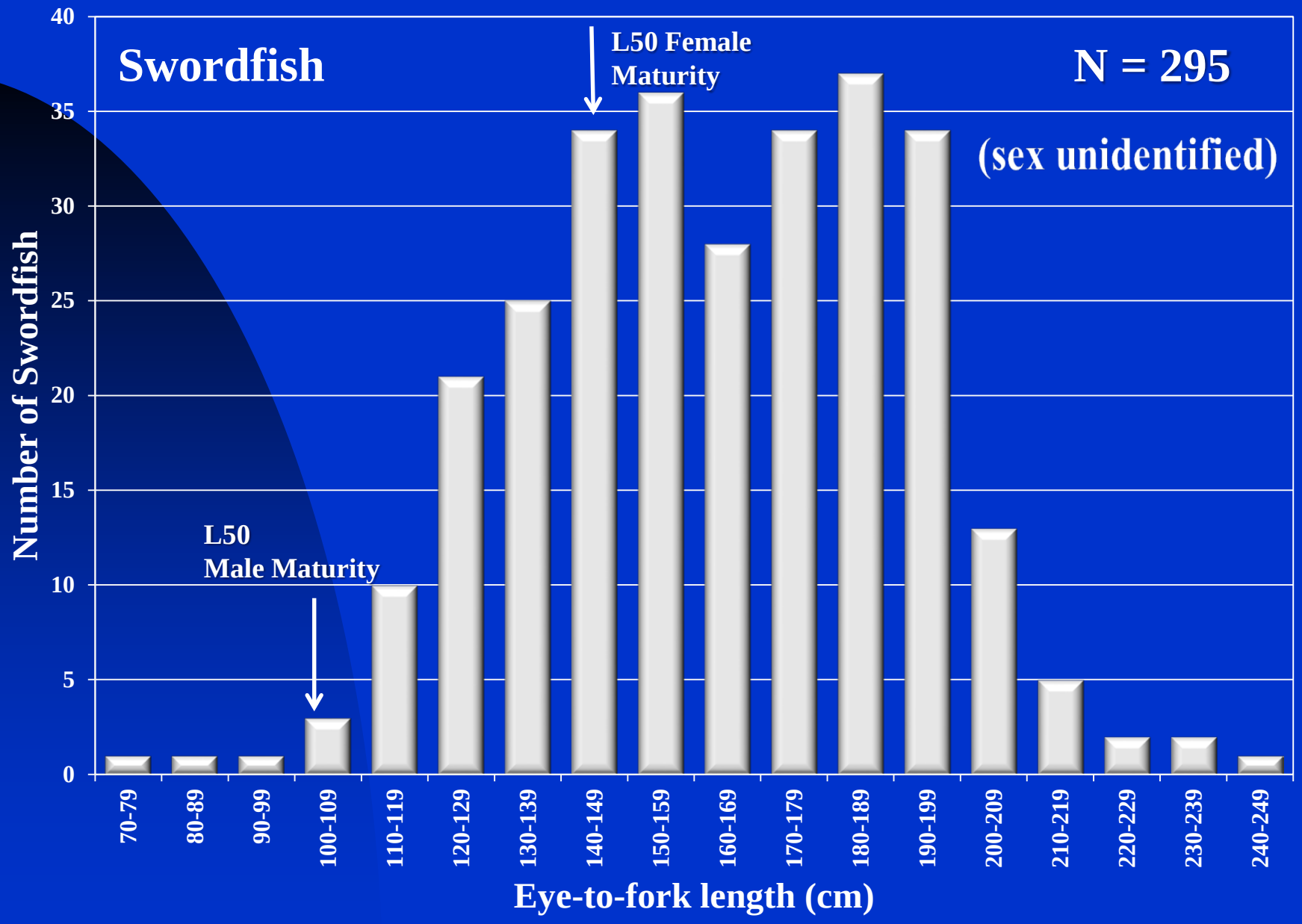
220-229
230-239
240-249
250-259
260-269
270-279
280-289
290-299
Fork Length (cm)


Swordfish
N = 295
(sex unidentified)
L50 Female Maturity
L50 Male Maturity
Number of Swordfish
0
5
10
15
20
25
30
35
40
70-79
80-89
90-99
100-109
110-119
120-129
130-139
140-149
150-159
160-169
170-179
180-189
190-199
200-209
210-219
220-229
230-239
240-249
Eye-to-fork length (cm)

Geometric Index of Importance
GII = (%W+%N+%F)/sqrt(3)

(to rank prey)

shortfin mako

366 stomachs w/food - 59 prey taxa

Prey Species	W (g)	N	F	GII
Jumbo squid, *Dosidicus gigas*	49597.65	135	88	**43.03**
Pacific saury, *Cololabis saira*	10781.45	642	90	**40.29**
Pacific sardine, *Sardinops sagax*	2155.82	170	39	**12.71**
Pacific mackerel, *Scomber japonicus*	3555.20	108	47	**12.67**
Striped mullet, *Mugil cephalus*	10914.80	32	29	**11.06**
Jack mackerel, *Trachurus symmetricus*	12298.61	31	24	**10.93**

GII – blue shark

156 stomachs w/ food - 46 prey taxa

Prey Species	W (g)	N	F	GII
Gonatus spp.	165.2	193	82	**40.52**
Jumbo squid, *Dosidicus gigas*	7480.9	42	28	**32.36**
Argonauta sp.	409.9	142	38	**21.98**
Flowervase jewell squid, *Histioteuthis dofleini*	30.5	105	41	**20.50**
Octopoteuthis sp.	42.6	117	36	**19.14**
Unidentified Euphausiidae	219.9	300	1	**14.22**

GII – thresher shark

434 stomachs w/ food - 31 prey taxa

Prey Species	W (g)	N	F	GII
Northern anchovy, *Engraulis mordax*	23197.2	2475	122	**55.29**
Pacific sardine, *Sardinops sagax*	15835.8	960	88	**31.91**
Unidentified Teleostei	5889.3	917	122	**28.70**
Market squid, *Doryteuthis opalescens*	3714.6	1065	99	**25.35**
Pacific hake, *Merluccius productus*	8958.3	412	70	**19.58**
Pacific mackerel, *Scomber japonicus*	9896.2	208	63	**17.53**

GII – bigeye thresher shark

45 stomachs w/food - 23 prey taxa

Prey Species	W (g)	N	F	GII
Jumbo squid, *Dosidicus gigas*	10124.0	27	13	**46.32**
Duckbill barracudina, *Magnisudis atlantica*	1484.7	68	12	**29.01**
Barracudinas, *Paralepididae*	1924.6	59	11	**27.54**
Pacific hake, *Merluccius productus*	1378.4	57	7	**20.73**
Unidentified Teleostei	234.1	34	7	**14.50**
Pacific mackerel, *Scomber japonicus*	462.6	15	8	**13.61**

GII – broadbill swordfish

292 stomachs w/ food - 60 prey taxa

Prey Species	W (g)	N	F	GII
Jumbo squid, *Dosidicus gigas*	131892.7	1061	173	**76.64**
Boreopacific gonate squid, *Gonatopsis borealis*	19949.8	884	182	**52.35**
Abraliopsis sp.	45.1	464	117	**28.25**
Gonatus spp.	181.6	299	110	**25.08**
Market squid, *Doryteuthis opalescens*	1447.6	538	88	**23.66**
Pacific hake, *Merluccius productus*	36360.1	331	49	**21.81**

Data Stratification (GII)

- by size classes
- by time periods / fishing seasons (DGN Aug-Jan)
- by area (east/west of 120°30’W)(inshore/offshore)

- Examine oceanography/El Niño/La Niña/regime shifts how these factors could explain the differences in diet in time/area (work in progress).

- A few highlights:

- **Mako sharks:**

  jumbo squid:

  -main prey 2002-2010 -in a few stomachs in 2012

  -NOT present in 2011 and 2013-2014

  Pacific saury: main prey in 2011 and 2013.

  Pacific saury:

  -ranked first for GII in small/medium makos

  large makos (150cm up FL) had jumbo squid as main prey.

- **Blue sharks:**
  - **also jumbo squid NOT present in 2011 and 2013 and only one specimen in 2012.**

- **Thresher sharks:**

  Northern anchovy:

  NOT present in 2002/2008/2012/2013/2014

- **Swordfish:**

  jumbo squid ranked low in 2011 and 2014 substituted by Pacific hake (!)

Multivariate Analyses (work in progress)

RDA - Redundancy Analysis

to extract and summarize the variation in a set of response variables that can be explained by a set of explanatory variables - (what drives the variations in diets quantitatively)

GAMs - Generalized Additive Models

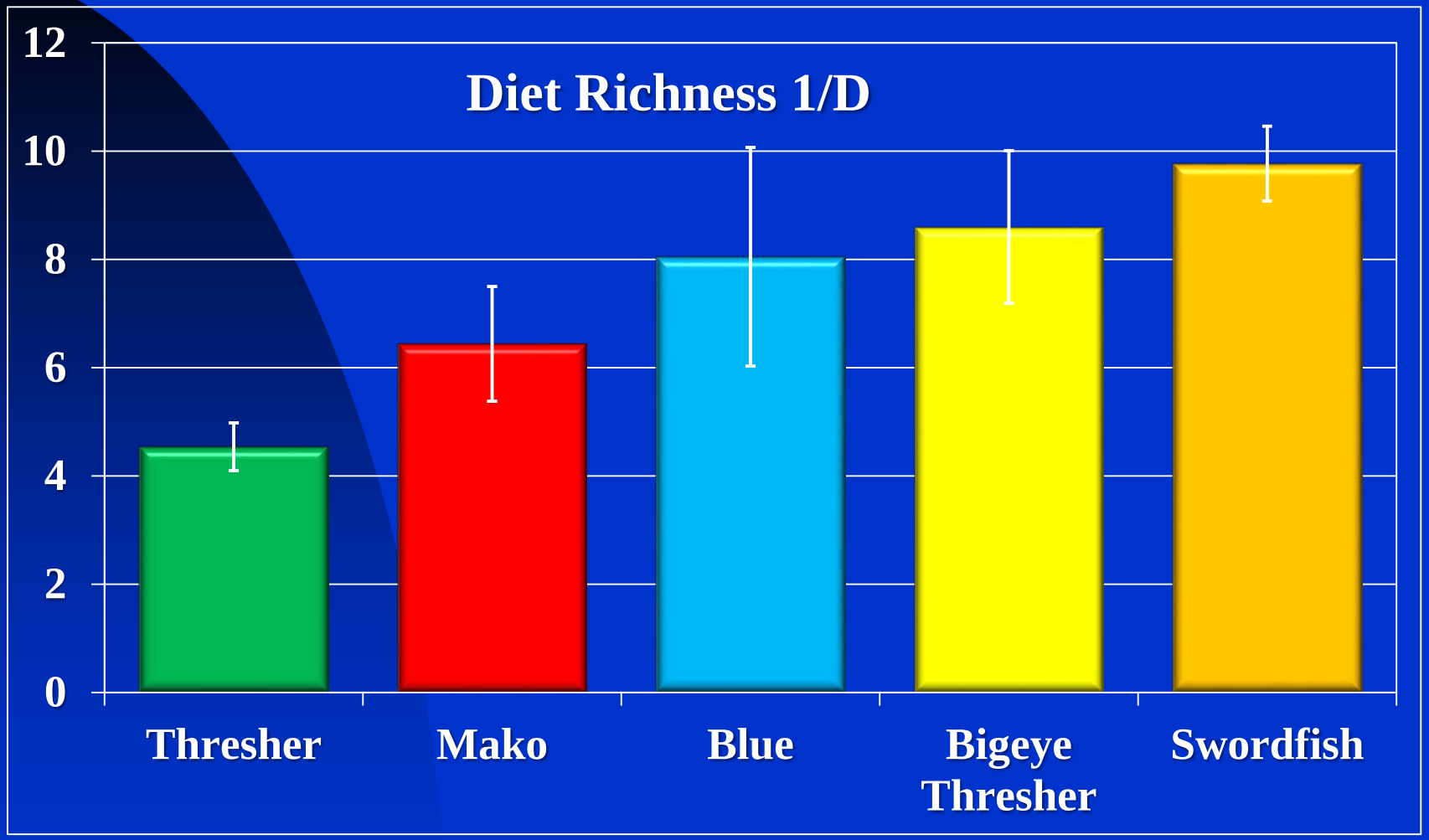
- **Predator types**
- **Prey types**
- **Years / sub-seasons**
- **Areas**
- **Predator size/ontogeny**
- **Sex**
- **Temperature/oceanographic variables**

Univariate Measures of Diets

different formulas / different 'angles'

- **Simpson** (diversity/richness)
- Menhinick (richness)
- Shannon entropy (diversity/inequality)
- Gini (inequality)
- **Sørensen** (similarity)
- Morisita-Horn - Simplified – SMH (overlap)
- **Pianka** (niche overlap)
- Levin (niche breadth)

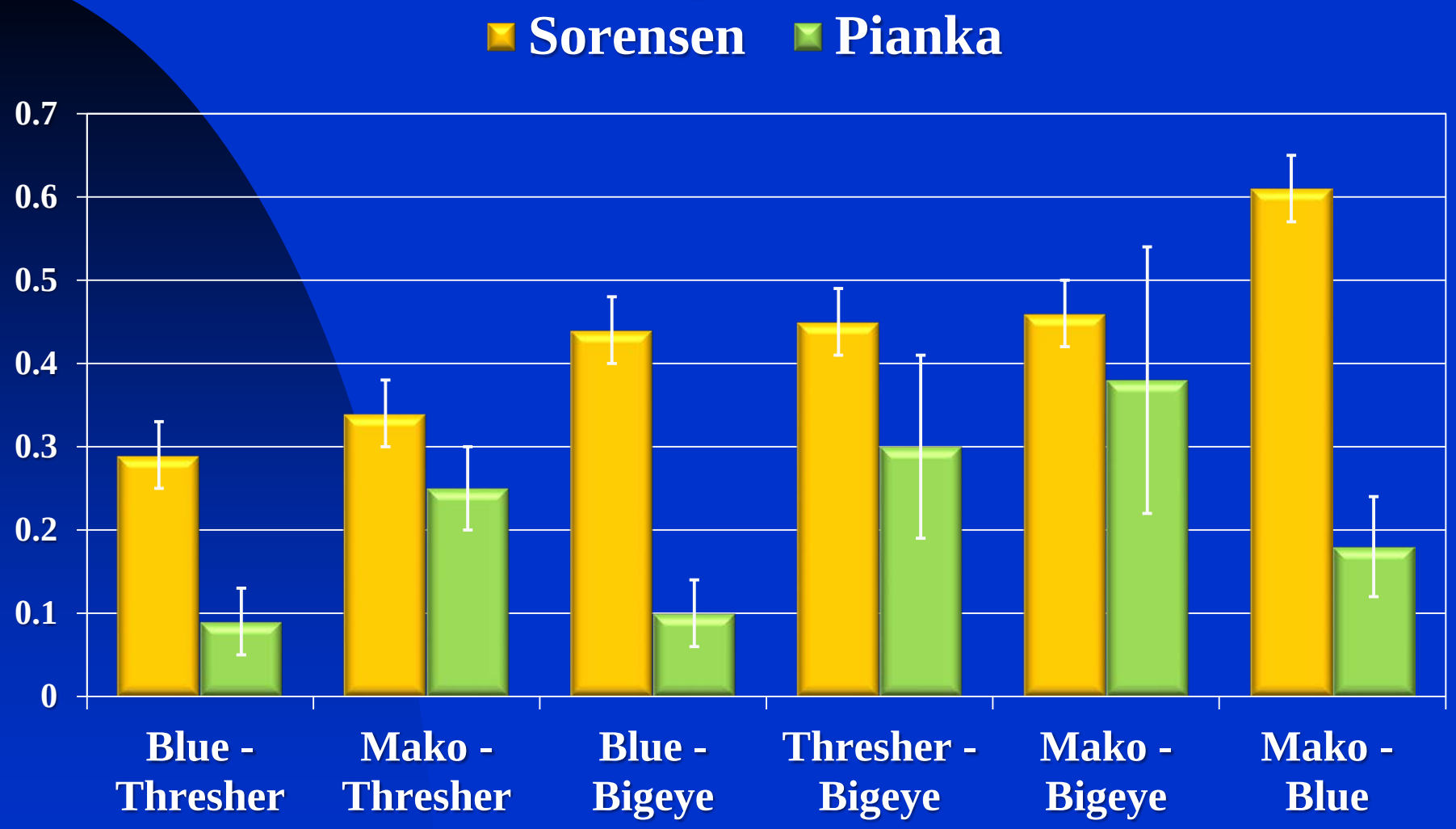
Simpson's (*D*) index of diversity / *(1/D)* richness



*mean value of the index based on 10000 bootstraps estimates; SE = std error

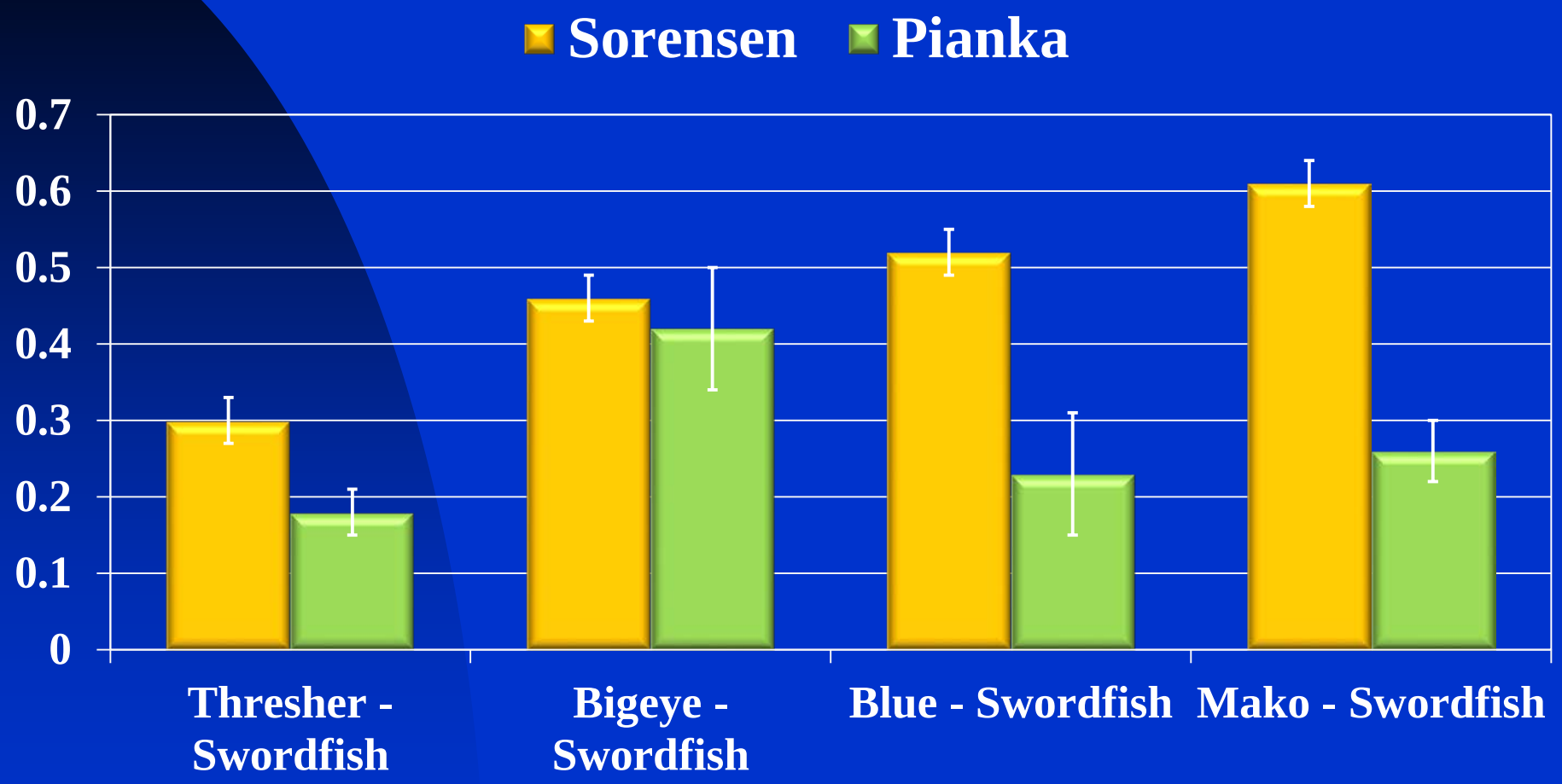
Sørensen Similarity of Diets (sharks) *(presence/absence of a prey item)

Pianka's Niche Overlap --(counts N)



Zero = no similarity / no overlap
One = identical diets / complete overlap

Sørensen Similarity of Diets
Pianka's Niche Overlap (sharks - swordfish)



Zero = no similarity / no overlap
One = identical diets / complete overlap

Time series : stomach samples (cetaceans)

Short-beaked common dolphin:

1990-2008 and 2010-2014

Long-beaked common dolphin: (<10 stom/year) (1992 / 1995/ 1997/ 2000 / 2002-2008 /2010-2013)

Northern right whale dolphin (*L. bor.*):

(1990-1997 / 1999-2004/ 2007-2008 / 2010-2013

Pacific white-sided dolphin (*L. obl.*):

(1991 / 2001-2002 / 2005 / 2007-2009)

Short-beaked common dolphin (*D. delphis*)

DGN (vials) 245 stomachs 60 prey taxa	N	F	GII 2 way
Abraliopsis sp.	5418	203	66.0
Gonatus spp.	2116	197	59.8
Dogtooth lampfish (*Ceratoscopelus townsendi)*	11351	147	58.0
Bigfin lanternfish (*Symbolophorus calif.)*	4914	161	53.2
Boreopacific gonate squid	1442	170	51.0
Onychoteuthis borealijaponica	1910	156	47.6

DGN (stom) 14 stomachs 40 prey taxa	W (g)	N	F	GII
Abraliopsis sp.	27.47	521	13	63.6
Bigfin lanternfish (*Symbolophorus calif.)*	8.07	617	11	55.8
Dogtooth lampfish (*Ceratoscopelus townsendi)*	2.69	453	11	52.8
Broadfin lampfish (*Lampanyctus ritteri)*	2.69	188	11	48.6
Pacific saury	519.44	78	4	47.8
Onychoteuthis borealijaponica	54.94	153	10	46.9

Long-beaked common dolphin (*D. capensis*)

DGN (vials) 14 stom 29 prey taxa	N	F	GII 2 way
Market squid	171	10	60.6
Pacific hake	256	6	48.4
Gonatus spp.	9	7	33.7
Northern anchovy	72	5	29.2
Broadfin lampfish	61	4	23.7
Bigfin lanternfish	21	4	20.5

DGN -2 stom -19 prey	W (g)	N	F	GII
Market squid	126.3	159	2	112.5
Eucarida	62.2	299	1	80.2
White croaker	6.2	1	1	30.8
California lizardfish (*Synodus luc.*)	0.1	17	1	30.8
Northern anchovy	0.1	16	1	30.7
Octopus rubescens	0.8	7	1	29.9

STRANDINGS (vials) 10 stom / 17 prey taxa	N	F	GII 2 way
Northern anchovy	295	6	69.1
Market squid	74	3	27.9
Pacific sardine	125	2	25.5
Gonatus spp.	17	3	22.8
Boreopacific gonate squid	53	2	18.9
Bigfin lanternfish	31	2	16.9

STRANDINGS 23 stom / 25 prey	W (g)	N	F	GII
Market squid	1336.96	1259	15	94.1
Northern anchovy	377	384	13	49.1
California lizardfish	9.71	418	12	38.6
Octopus rubescens	6.82	483	10	34.7
Pacific sardine	208.59	142	10	32.8
Pacific mackerel	319.53	19	3	15.5

Northern right whale dolphin (*L. borealis*)

DGN (vials) 51 stomachs 48 prey taxa	N	F	GII 2 way
Abraliopsis sp.	1874	49	75.9
Gonatus spp.	831	48	70.1
California headlightfish (*Diaphus theta*)	2595	41	67.9
Onychoteuthis borealijaponica	1180	45	67.4
Boreopacific gonate squid	369	46	65.4
Bigfin lanternfish	1482	40	61.8

DGN - 5 stomachs 31 prey taxa	W (g)	N	F	GII
Market squid	617.36	144	5	86.8
California smoothtongue (*Leuroglossus stilbius*) Bathylagidae	31.51	161	6	75.1
Abraliopsis sp.	78.06	350	5	70.8
Gonatus spp.	180.88	153	5	69.4
Dogtooth lampfish	1.74	276	5	65.7
Mexican lampfish (*Triphoturus mexicanus*)	2.68	266	5	65.4

Pacific white-sided dolphin (*L. obliquidens*)

DGN (vials) 23 stomachs 37 prey taxa	N	F	GII 2 way
Market squid	425	13	50.1
Boreopacific gonate squid	319	11	41.4
Abraliopsis sp.	155	12	40.6
Gonatus spp.	221	11	39.1
Onychoteuthis borealijaponica	156	11	37.5
Bigfin lampfish	230	9	33.1

STRANDINGS (vials) 2 stomachs 5 prey taxa	N	F	GII 2 way
Market squid	14	1	68.4
Northern anchovy	9	1	56.6
Plainfin midshipman (*Porichthys notatus*) Batrachoididae	5	1	47.1
White croaker	1	1	37.7
Teleostei	1	1	37.7

Stable Isotope Analysis (SIA)

Stomach content analysis (SCA) : a snapshot of diet.

SIA provides temporally integrated information (weeks to months) on dietary habits, reflecting foods assimilated by the consumer.

SCA provides info on taxonomy / size composition of prey and 'predator–prey interactions' in complex systems, where predators consume a diversity of items that may be difficult to identify from stable isotope ratios alone.

A combination of SIA and SCA is increasingly being used to improve interpretation of feeding studies and aquatic food webs.

Stable Isotope Analysis (SIA)

2011/2012 Dorsal muscle tissue

Predators:

Shortfin mako (*Isurus oxyrinchus*) n=28

Blue shark (*Prionace glauca*) n=30

Thresher shark (*Alopias vulpinus*) n=23

Broadbill swordfish (*Xiphias gladius*) n=19

Prey (samples in the stomachs in fresh state of digestion)

Jumbo squid (*Dosidicus gigas*) n=22

Pacific hake (*Merluccius productus*) n=16

Market squid *(Doryteuthis opalescens)* n=14

***Gonatopsis borealis* n=14**

Pacific saury (*Cololabis saira*) n=13

Pacific sardine (*Sardinops sagax*) n=13

Pacific mackerel (*Scomber japonicus*) n=10

Duckbill barracudina (*Magnisudis atlantica*) n=8

Jack mackerel *(Trachurus symmetricus)* n=3

***Onychoteuthis borealis* n=2**

Pacific pomfret (*Brama japonica*) n=2

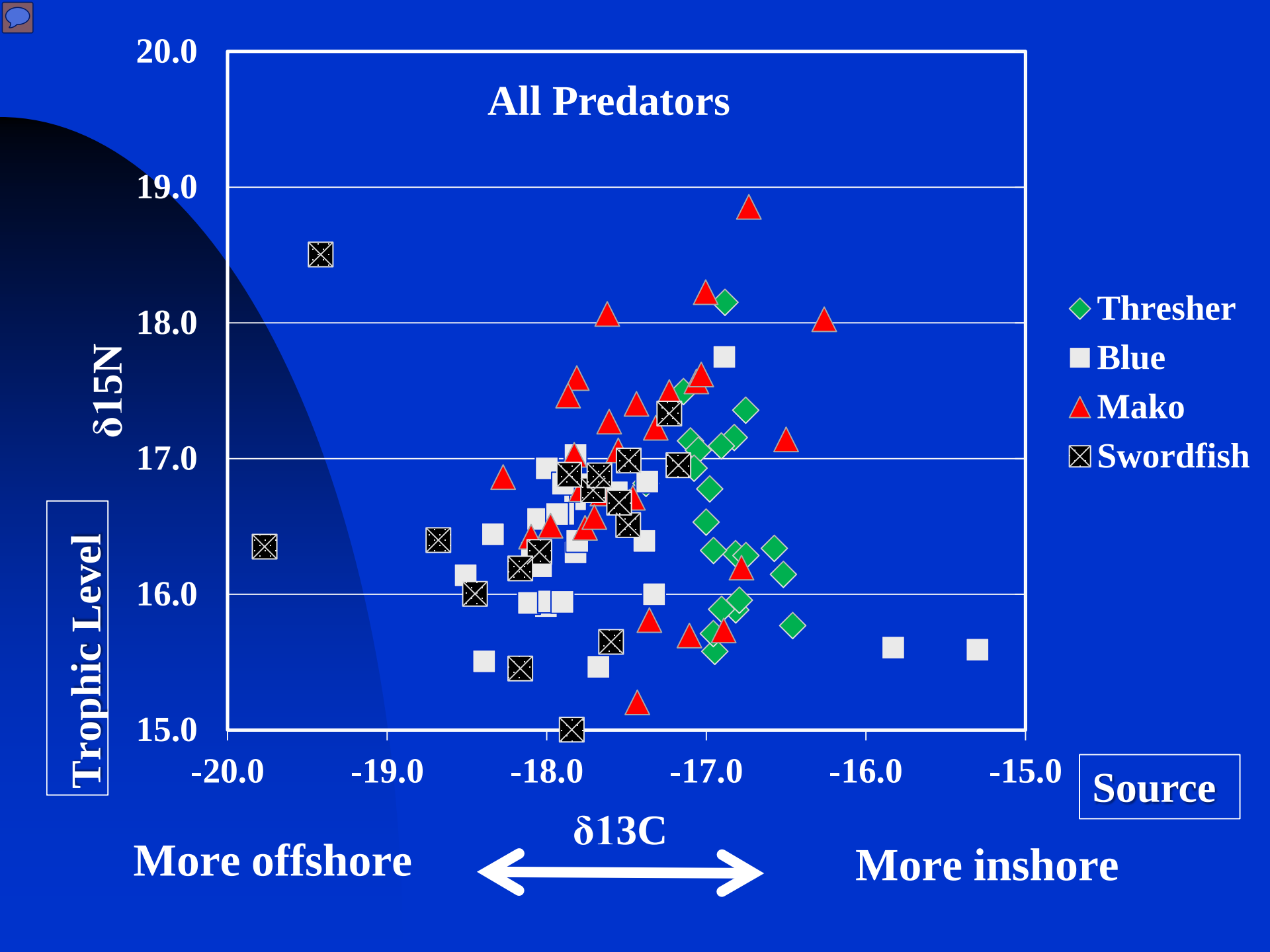
Chubby pearleye (*Rosenblattichthys volucris*) n=2

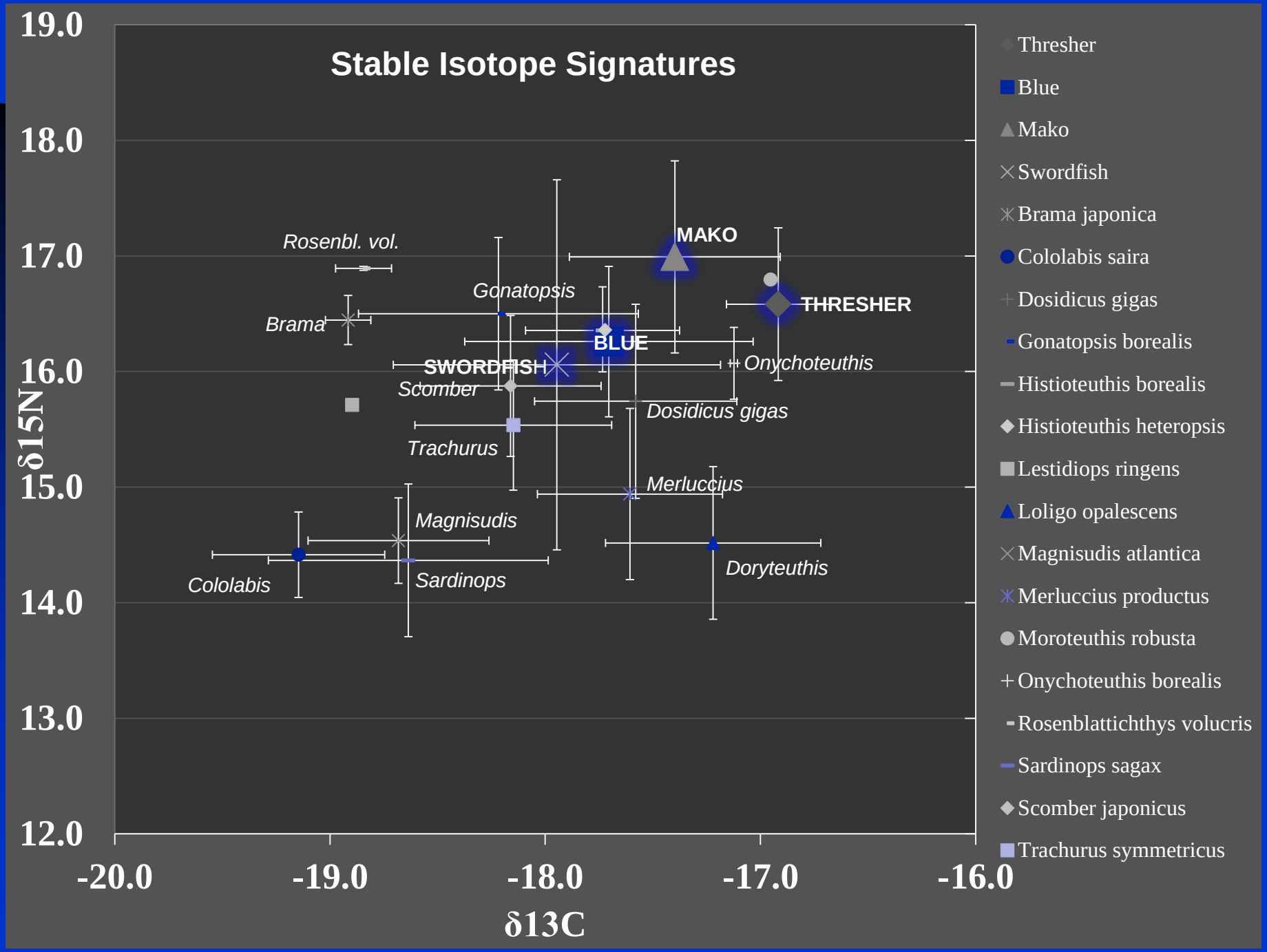
***Histioteuthis borealis* n=2**

***Histioteuthis heteropsis* n=1**

Slender barracudina (*Lestidiops ringens*) n=1

***Moroteuthis robusta* n=1**


All Predators
20.0
19.0
18.0
17.0
16.0
15.0
δ15N
Trophic Level
-20.0
-19.0
-18.0
-17.0
-16.0
-15.0
δ13C
Source
More offshore
More inshore
Thresher
Blue
Mako
Swordfish


Stable Isotope Signatures
19.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
δ15N
-20.0
-19.0
-18.0
-17.0
-16.0
δ13C
Rosenbl. vol.
Brama
Gonatopsis
MAKO
THRESHER
BLUE
SWORDFISH
Scomber
Onychoteuthis
Dosidicus gigas
Trachurus
Merluccius
Magnisudis
Cololabis
Sardinops
Doryteuthis
Thresher
Blue
Mako
Swordfish
Brama japonica
Cololabis saira
Dosidicus gigas
Gonatopsis borealis
Histioteuthis borealis
Histioteuthis heteropsis
Lestidiops ringens
Loligo opalescens
Magnisudis atlantica
Merluccius productus
Moroteuthis robusta
Onychoteuthis borealis
Rosenblattichthys volucris
Sardinops sagax
Scomber japonicus
Trachurus symmetricus