

Classification of free-ranging Weddell seal dives
based on three-dimensional movements and video-
recorded prey capture

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Objective: Determine how Weddell seals search for, detect and capture prey and how these behaviors vary with location, season, prey type and environmental conditions

1997-99 Isolated ice hole paradigm during the austral summer

2001-02 Free-ranging seals during the austral summer

2008-10 Free-ranging seals during late winter

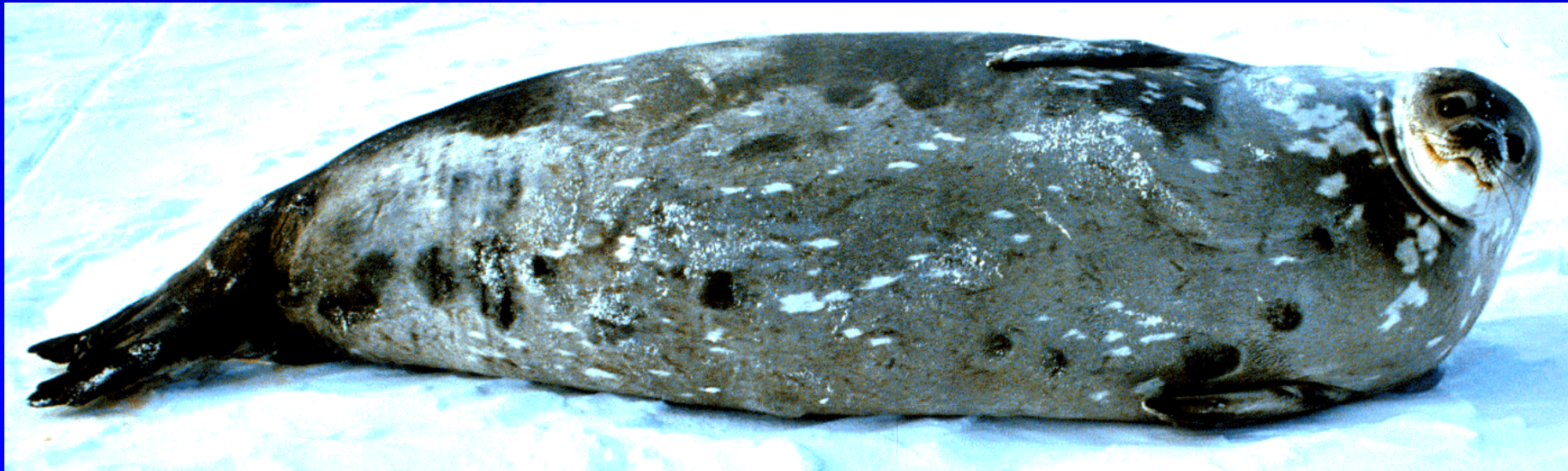
The goal of this study: Classify and compare free-ranging dives of Weddell seals with those from an isolated ice hole during the austral summer using descriptors for three-dimensional dive path and a multivariate classification scheme.

Weddell seal (*Leptonychotes weddellii*)

Adult body mass: 350-550 kg

Body length: 2.3-3.0 m

Males and females are about the same size



Problem: How do we observe hunting behavior and prey capture in deep diving marine mammals?

Stalk



Attack



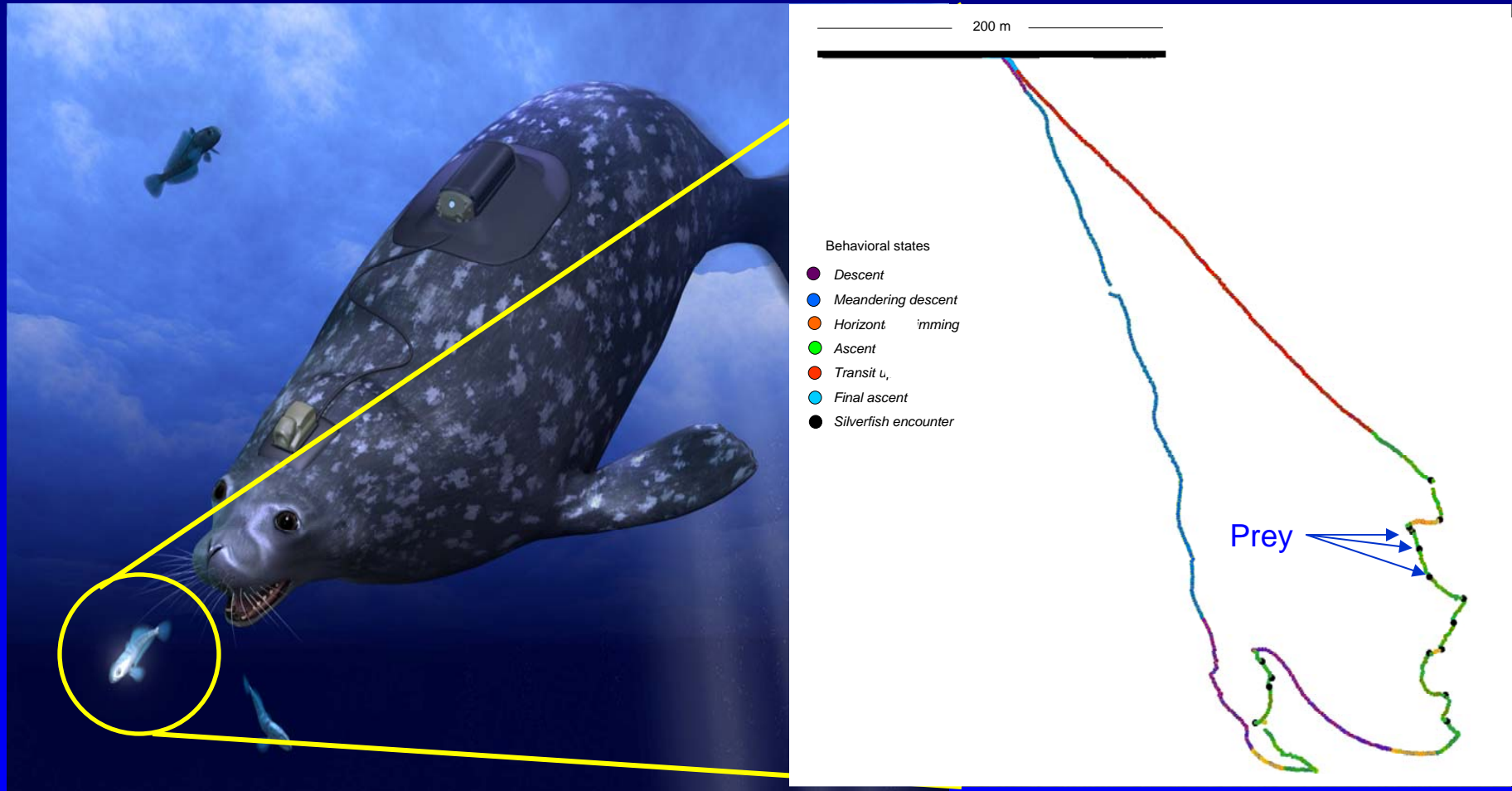
Prey handling



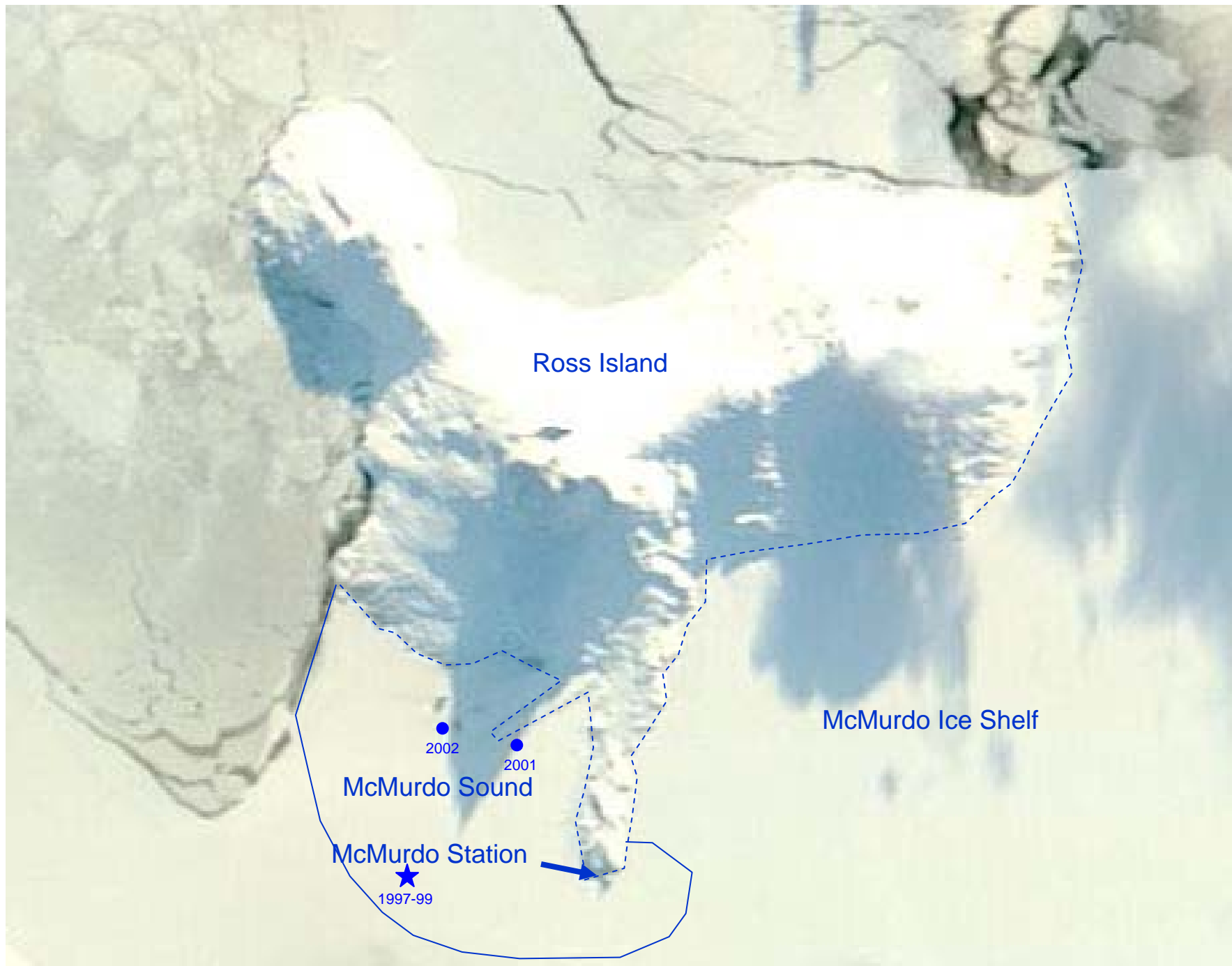
Prey capture



We used animal-borne video and data recorders that could determine three-dimensional movements and video record predator-prey interactions.



Simultaneously record data to calculate the 3D dive path, swim speed, stroke frequency, sound and environmental variables



1997-99 Isolated ice hole paradigm during the austral summer



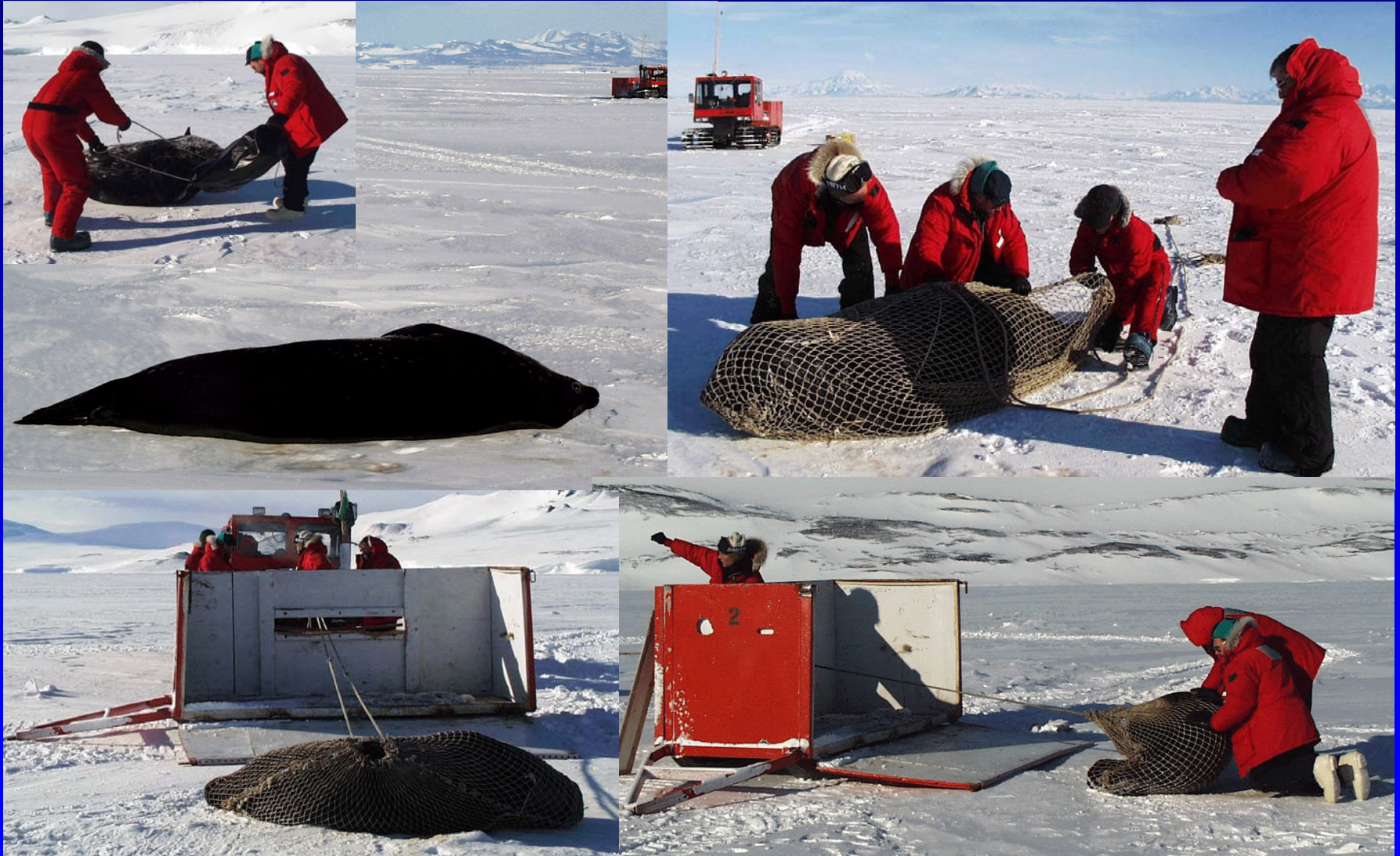
2001-02 Free-ranging seals during the austral summer

Tent Island

Sea ice camp

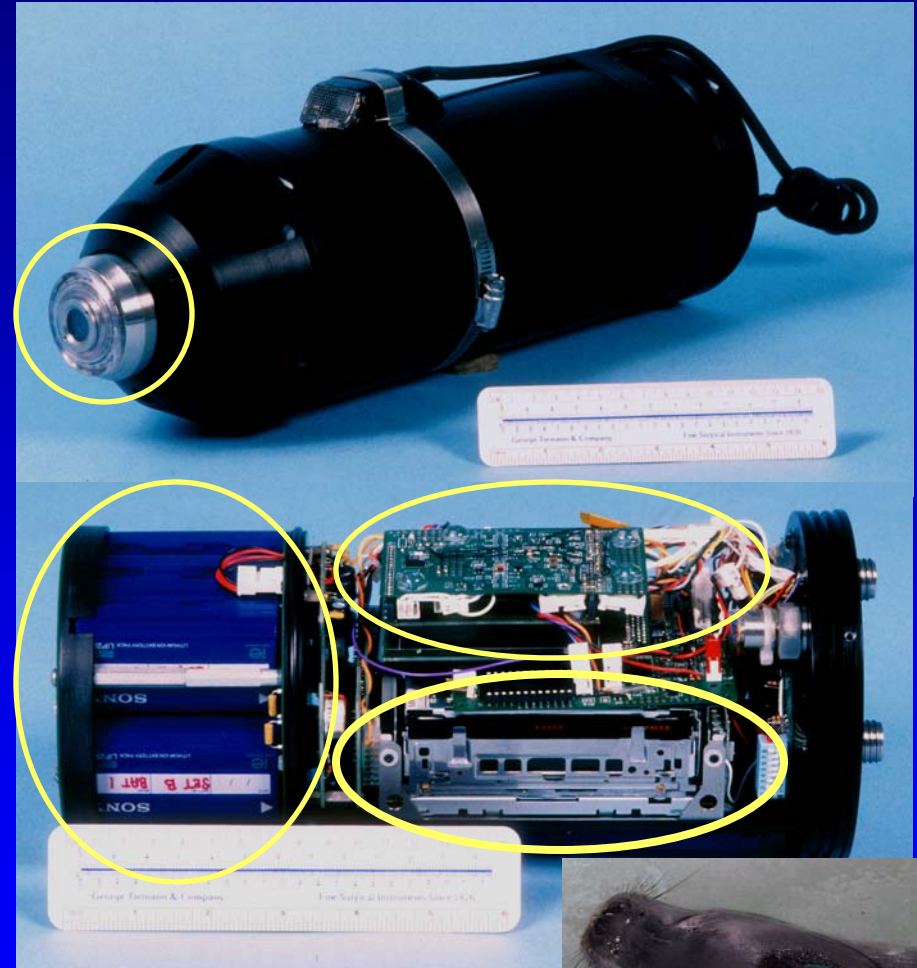


Capturing a Weddell seal on the sea ice



Video and data recorder: Generation III (1997-2002)

- 1,000-m depth rating
- B&W CCD camera
- Near infrared light source
- 8 mm video recorder: 30 fps, 6-hr duration
- Microprocessor
- 128 MB Compact Flash memory card for data storage
- Li-ion rechargeable batteries
- Transducers: depth, speed, compass bearing, temp., flipper stroke freq., sound





Antarctic silverfish (*Pleuragramma antarcticum*)



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040145



Spatial and temporal variables from 3-D dive paths

Spatial (total dive, outbound leg, inbound leg)

1. Total dive distance traveled
2. Far point distance
3. Mean depth
4. Mean maximum depth
5. Linearity of dive path (net-to-gross displacement ratio)
6. Mean compass bearing
7. Mean vertical angle

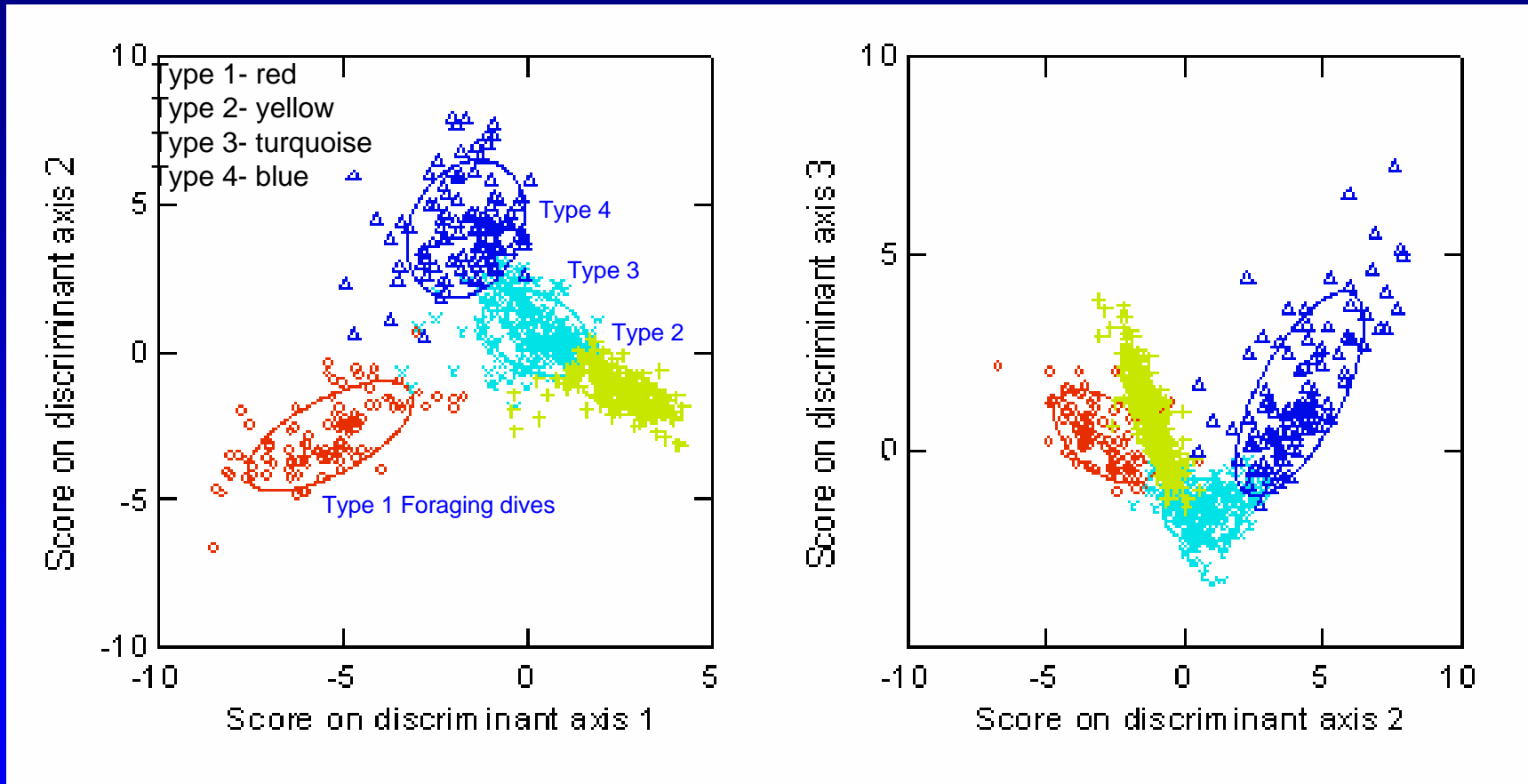
Temporal (total dive, outbound leg, inbound leg)

1. Duration
2. Far point time
3. Duration below a certain depth

Spatial-temporal (total dive, outbound leg, inbound leg)

1. Mean speed
2. Maximum speed

Classification of dives based on 58 spatial and temporal variables from 3-D dive paths from isolated-hole paradigm during the austral summer

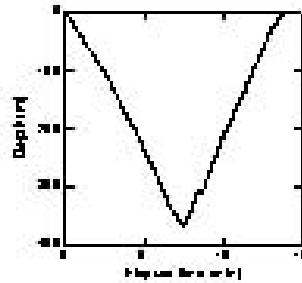
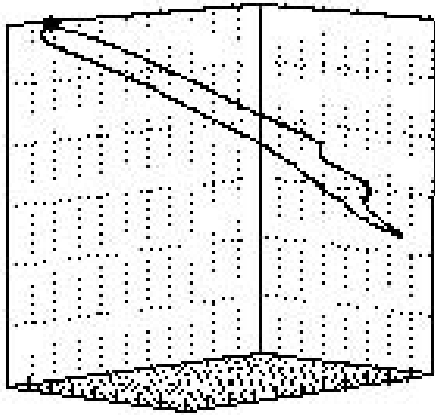


- 1st discriminant axis separated clusters primarily according to swimming path linearity and distance.
- 2nd discriminant axis separated clusters primarily according to dive duration and distance.
- 3rd discriminant axis separated clusters primarily according to dive duration, distance traveled, and swimming speed.

Type 1



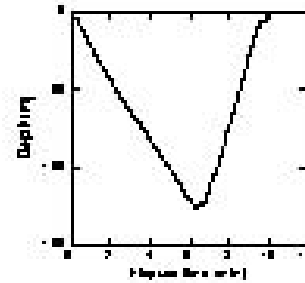
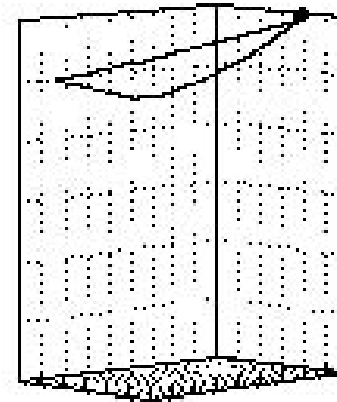
Mean max depth = 378 m
 Mean duration = 15.0 min
 Mean speed = 2.1 m/s
 Steep descent/ascent
 NGDP low
 Far Pt Dist = 671 m



Type 3

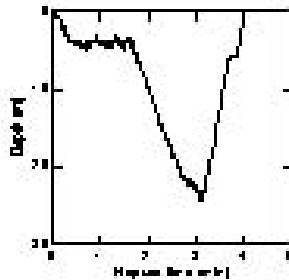
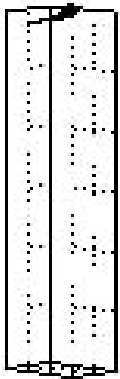
Mean max depth = 81 m
 Mean duration = 7.9 min
 Mean speed = 1.8 m/s

Shallow descent/ascent
 NGDP intermediate
 Far Pt Dist = 375 m



Type 2

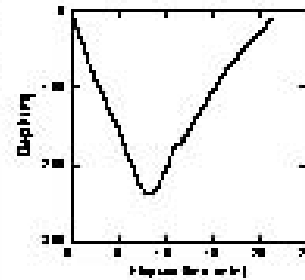
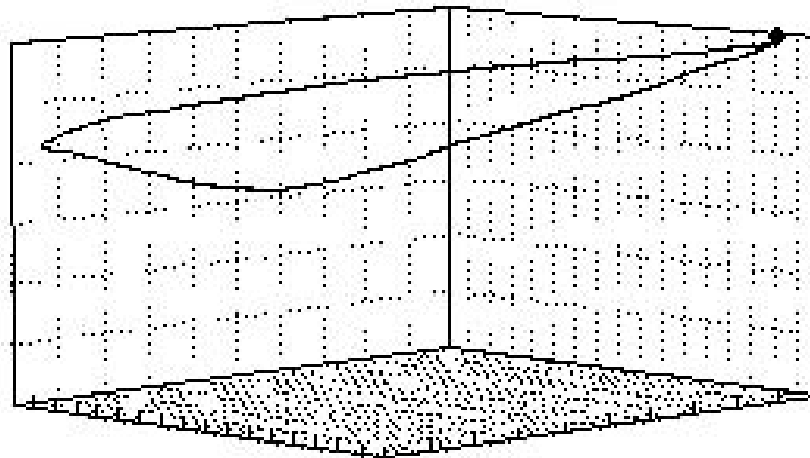
Mean max depth = 30 m
 Mean duration = 3.6 min
 Mean speed = 1.1 m/s
 Shallow descent/ascent
 NGDP very low
 Far Pt Dist = 75 m



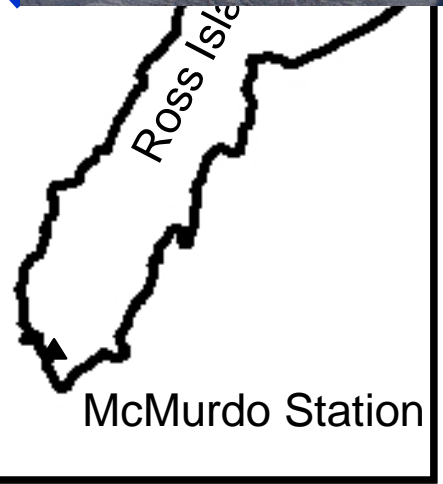
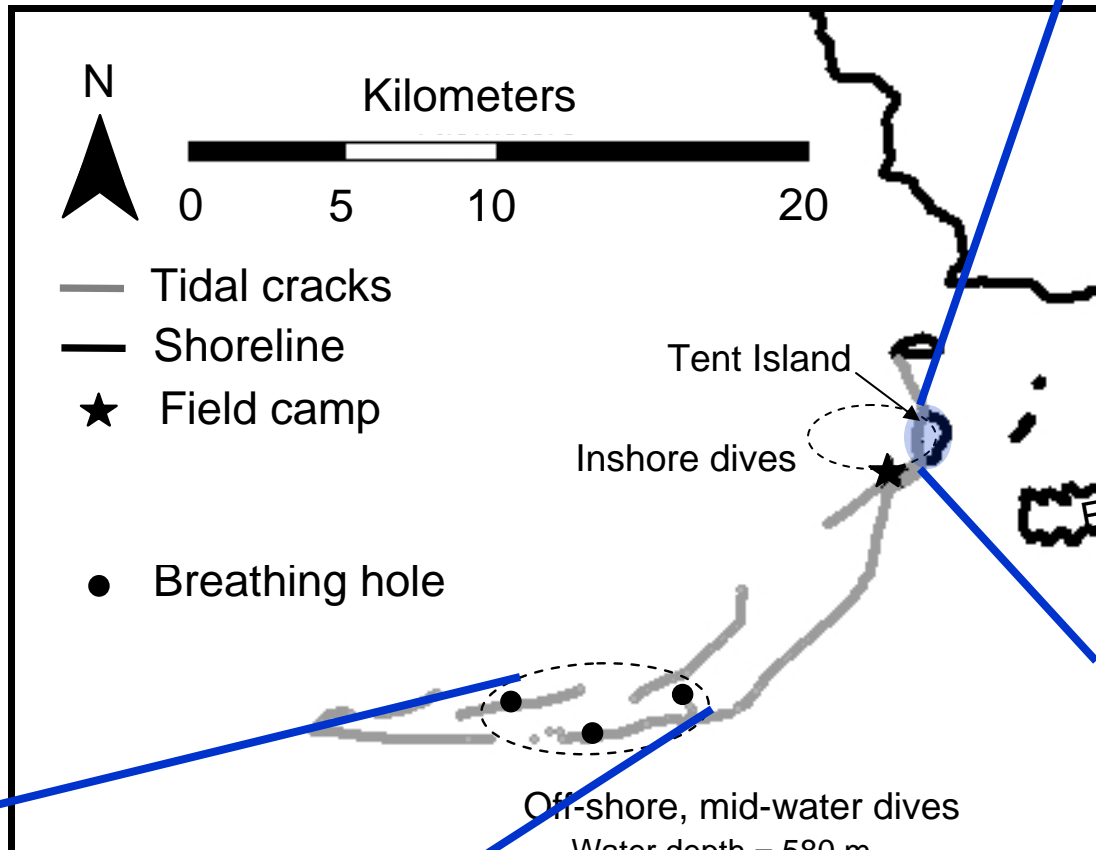
Type 4

Mean max depth = 142 m
 Mean duration = 24.7 min
 Mean speed = 2.2 m/s

Shallow descent/ascent
 NGDP high
 Far Pt Dist = 1,465 m

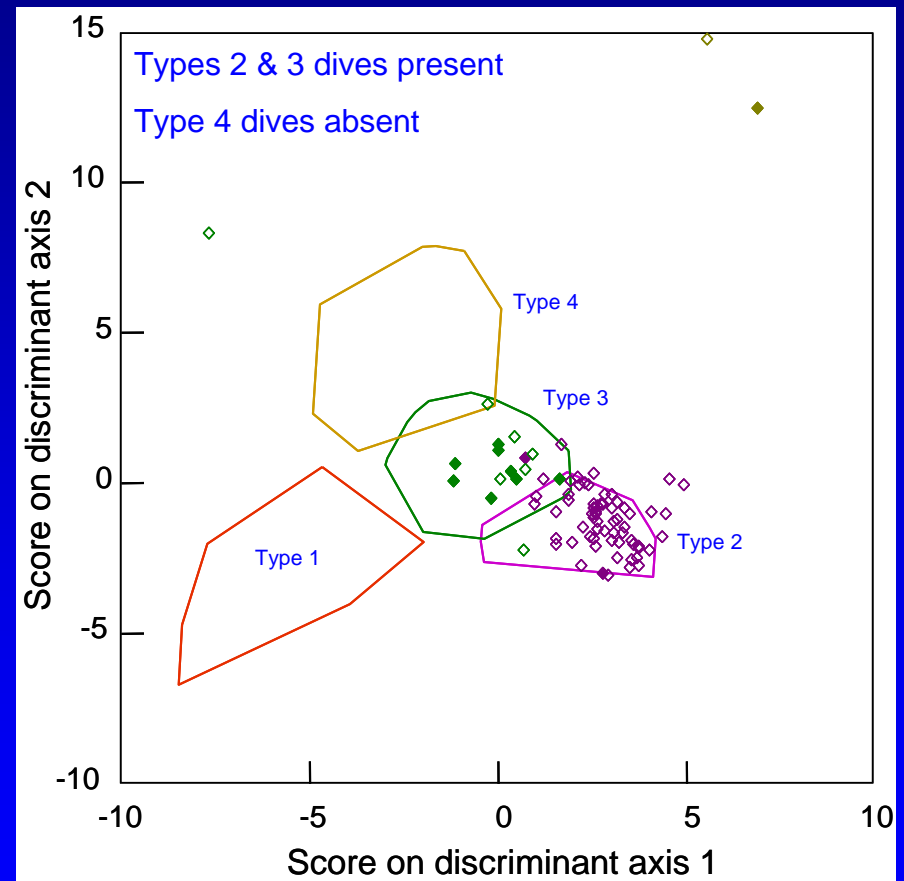
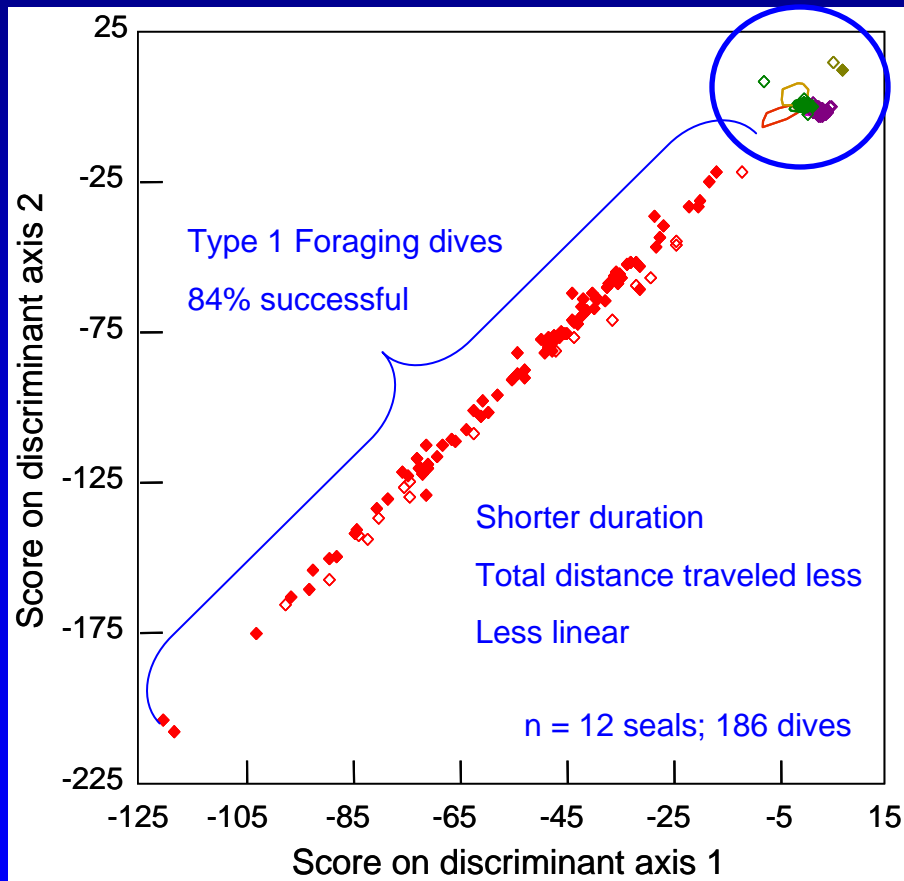


Free-ranging seals



Study area within McMurdo Sound

Classification of off-shore, deep water dives for free-ranging seals during the austral summer based on the 58 spatial and temporal variables



200 m

Midwater foraging dive showing four foraging states: search, pursuit, attack, and handling

Colors indicate different foraging states

- Search
- Pursuit
- Attack
- Handling

Non-foraging states

- Pre-foraging
- Post-foraging

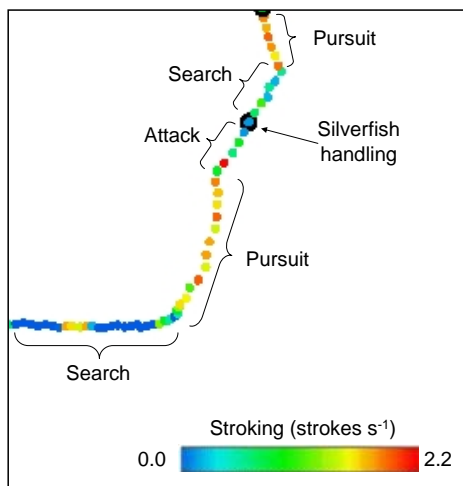
Energy expended per dive 619 kJ
Energy gain in fish per dive 5,200 kJ
Net gain 4,581 kJ
Efficiency 840%

Pleuragramma captures



Average Dive Characteristics

Prey capture	16
Max depth	336 m
Dive duration	15.7 min
Total distance	1,475 m
Swim speed	1.6 m
Stroke rate	0.92 Hz
Total strokes	832
Energetic cost	68 ml O ₂ kg ⁻¹
Energetic rate	4.4 ml O ₂ kg ⁻¹ min ⁻¹
Time gliding	1.4 min



Colors in inset indicate stroking rate

Inshore foraging dive from the coast of Tent Island

Average Dive Characteristics

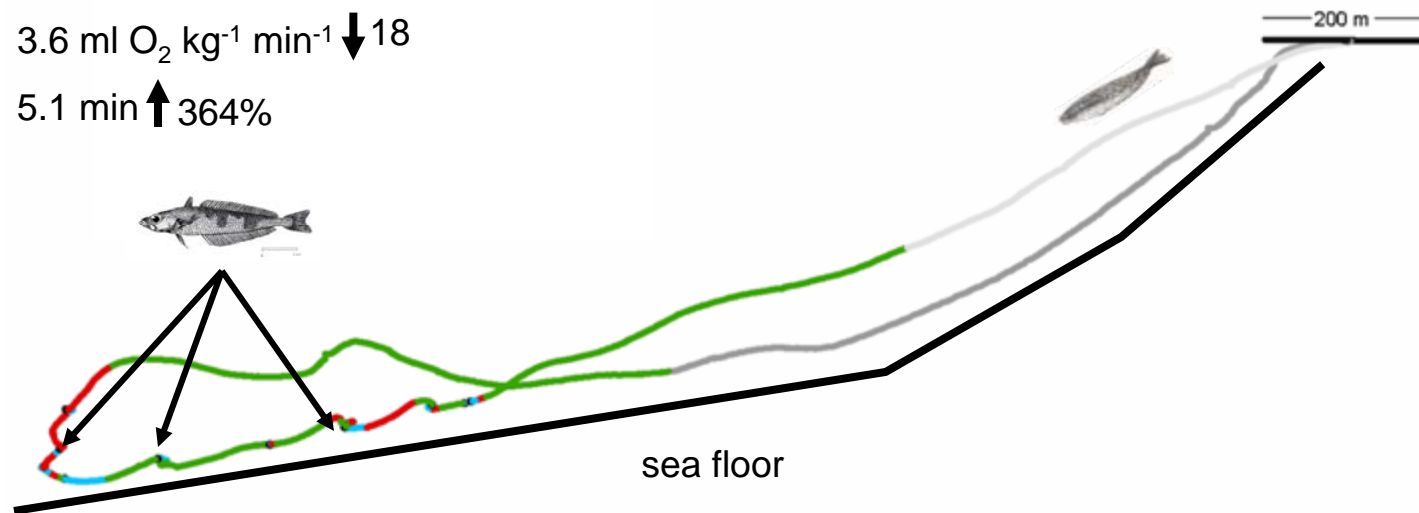
Prey capture	3 ↓81%
Max depth	230 m ↓32%
Dive duration	22.3 min ↑42%
Total distance	1,807 m ↑23%
Swim speed	1.3 m ↓19%
Stroke rate	0.62 Hz ↓33%
Total strokes	843 no change
Energetic cost	82 ml O ₂ kg ⁻¹ ↑21%
Energetic rate	3.6 ml O ₂ kg ⁻¹ min ⁻¹ ↓18
Time gliding	5.1 min ↑364%

Energy expended per dive	746 kJ
Energy gain from fish per dive	975 kJ
Net gain	229 kJ
Efficiency	130%

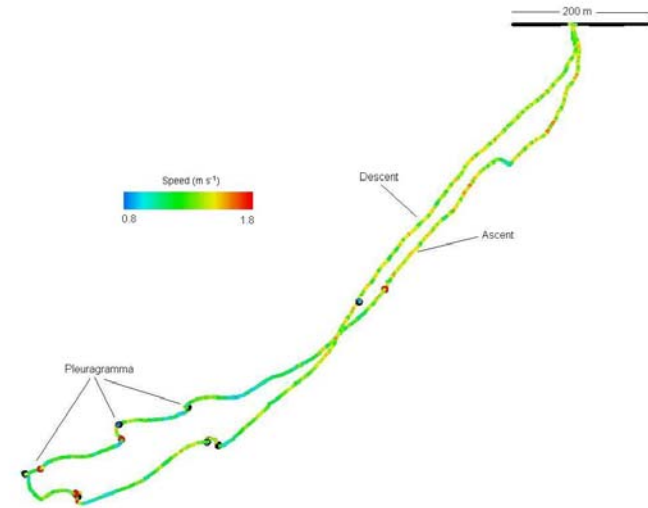
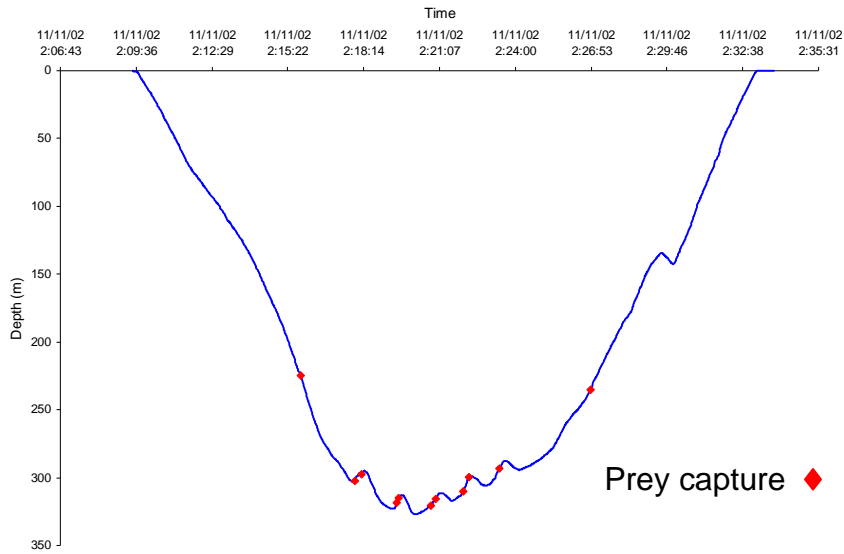
Inshore foraging is more costly and results in less energy intake

Why would seals forage inshore?

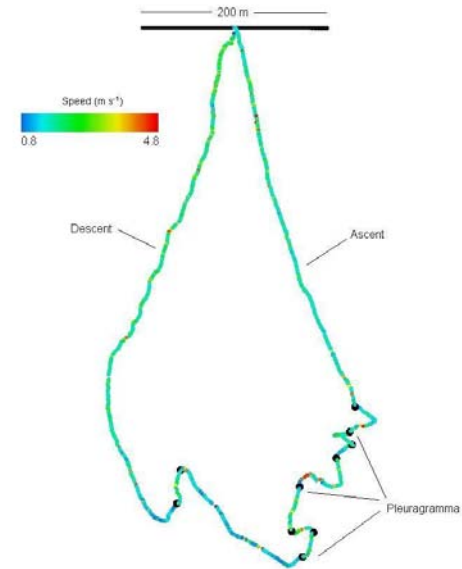
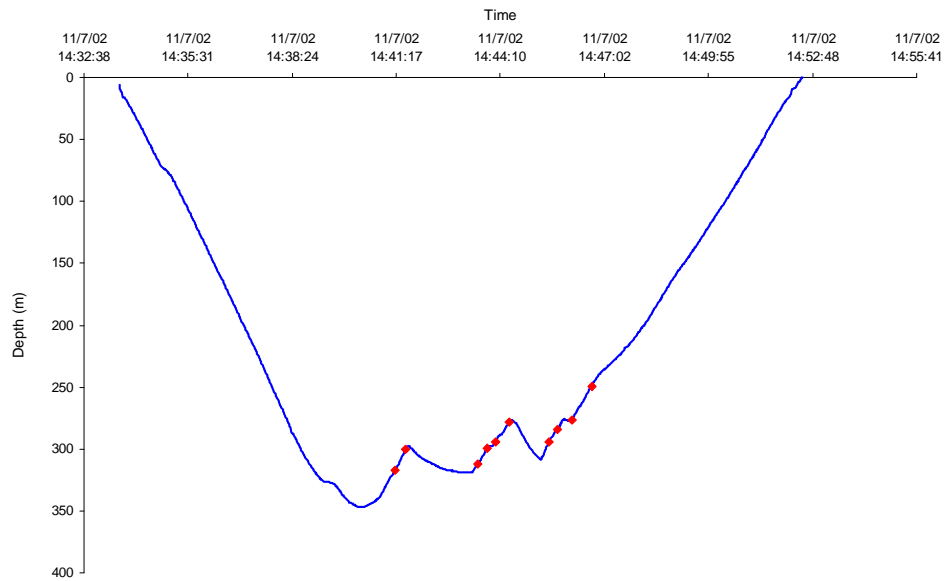
Reproductive behavior vs. foraging behavior



Inshore foraging dive



Offshore, deep-water foraging dive



Conclusions

The characteristics of dives for free-ranging Weddell seals foraging off-shore over deep water differs from that of seals diving from an isolated-hole

- 1) Shorter range from the breathing hole
- 2) Slower swim speed
- 3) The outbound and inbound dive paths are less linear
- 4) However, foraging dives at both locations are well within the aerobic dive limit of 15-17 min

The characteristics of dives for seals foraging inshore differs from off-shore foraging dives over deep water

- 1) Dive duration is significantly (1.6x) longer and close to the ADL
- 2) Total distance traveled is greater and dive paths were more linear
- 3) Fewer prey captures (less efficient)

Weddell seals occur in different areas for a variety of reasons, some of which may affect apparent foraging success. Age, reproductive status and season must be considered when assessing foraging behavior and efficiency.

Continuing research of foraging behavior of Weddell seals during the late winter when ambient light levels are very low will probably reveal additional dive categories.



Acknowledgments

Instrument Design and Fabrication

William Hagey

Video Analysis

Maria Davis

Graduate Students

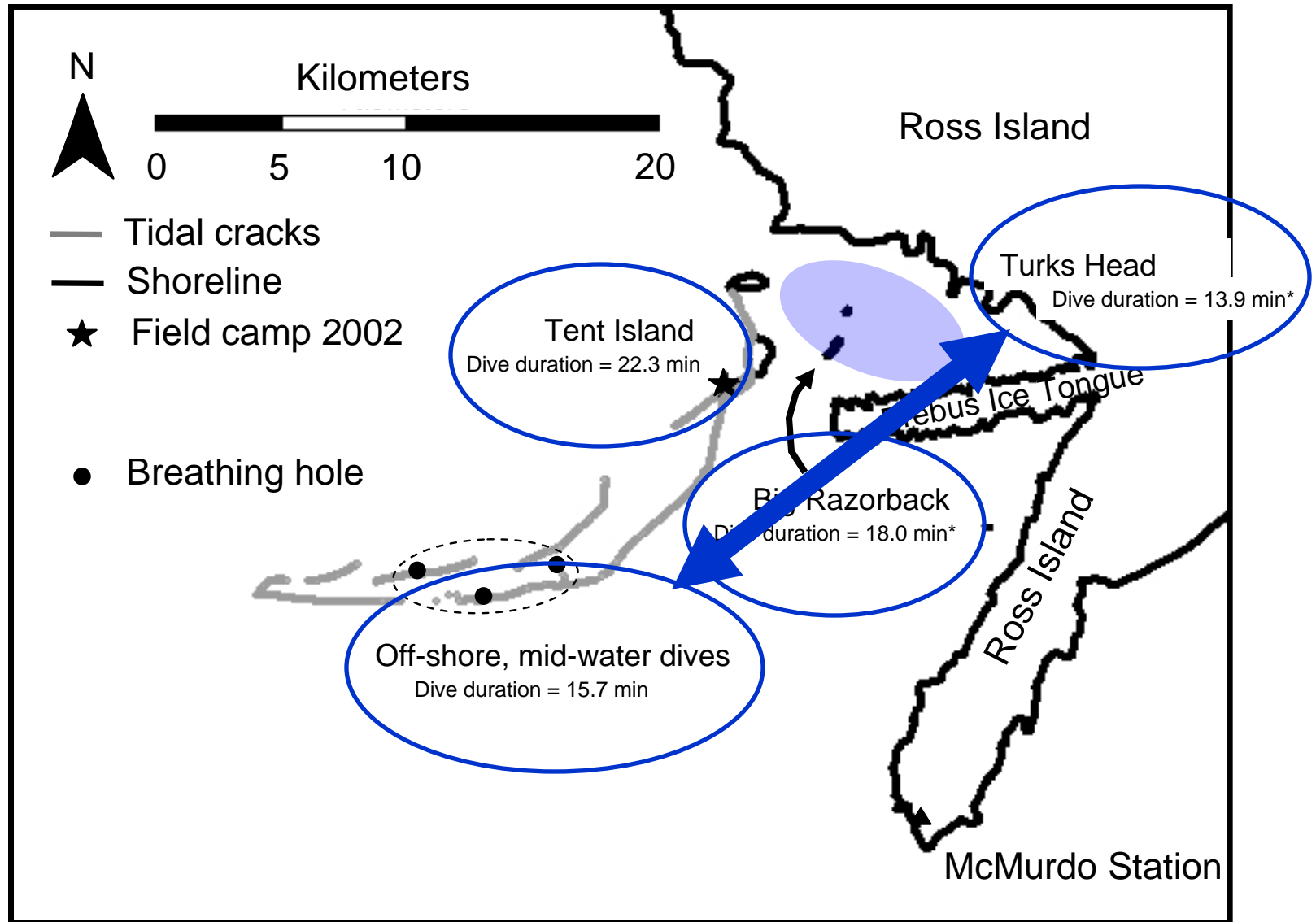
Kiersten Madden, Ludivine Rousseau

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*Sato et al., 2003

Descriptor	Offshore free-ranging			Inshore free-ranging		
Elapsed time to far point (sec)* TIME_FARPT	500.5	±	14.8	740.7	±	28.8
Dive duration (min) DURA_MIN	16.7	±	0.5	24.7	±	1.0
Max. distance from hole (m)* FARPNT_DIST	471.5	±	12.3	743.2	±	47.9
Inbound distance traveled (m) INDIST_TOT	741.9	±	15.5	984.9	±	58.5
Outbound distance traveled (m) OUTDIST_TOT	707.9	±	15.0	961.5	±	46.5
Mean speed (m sec⁻¹) SPEED_MN	1.48	±	0.02	1.30	±	0.03
Inbound horizontal path linearity INXY_NGDR	0.55	±	0.02	0.76	±	0.03
Inbound path linearity INXYZ_NGDR	0.64	±	0.01	0.75	±	0.02
Outbound horizontal path linearity OUTXY_NGDR	0.64	±	0.02	0.75	±	0.03
Outbound path linearity OUTXYZ_NGDR	0.67	±	0.01	0.75	±	0.02
N	73			32		

Classification success (%) using fewer variables

Dive type	Tree based on mean depth, far point distance, and mean speed	Tree based on mean depth, distance, and mean speed
1	90	90
2	94	94
3	40	40
4	0	0

200 m

Off-shore, deep water foraging dive showing four foraging states: search, pursuit, attack and handling

Colors indicate different foraging states

- Search
- Pursuit
- Attack
- Handling

Non-foraging states

- Pre-foraging
- Post-foraging

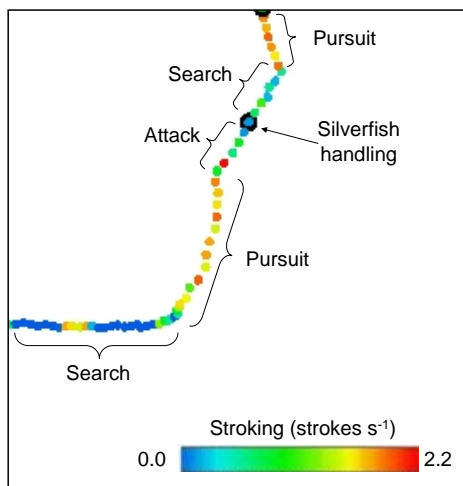
Pleuragramma captures



Energy content = 325 kJ

Average Dive Characteristics

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Max depth	336 m
Dive duration	16.7 min
Total distance	1,450 m
Swim speed	1.5 m
Stroke rate	0.92 Hz
Total strokes	832
Energetic cost	68 ml O ₂ kg ⁻¹
Energetic rate	4.4 ml O ₂ kg ⁻¹ min ⁻¹
Time gliding	1.4 min



Colors in inset indicate stroking rate

Figure courtesy of Kiersten Madden

Structure of a foraging dive along the western coast of Tent Island

Energy expended per dive 746 kJ
 Energy gain from fish per dive 975 kJ
 Net gain 229 kJ
 Efficiency 130%

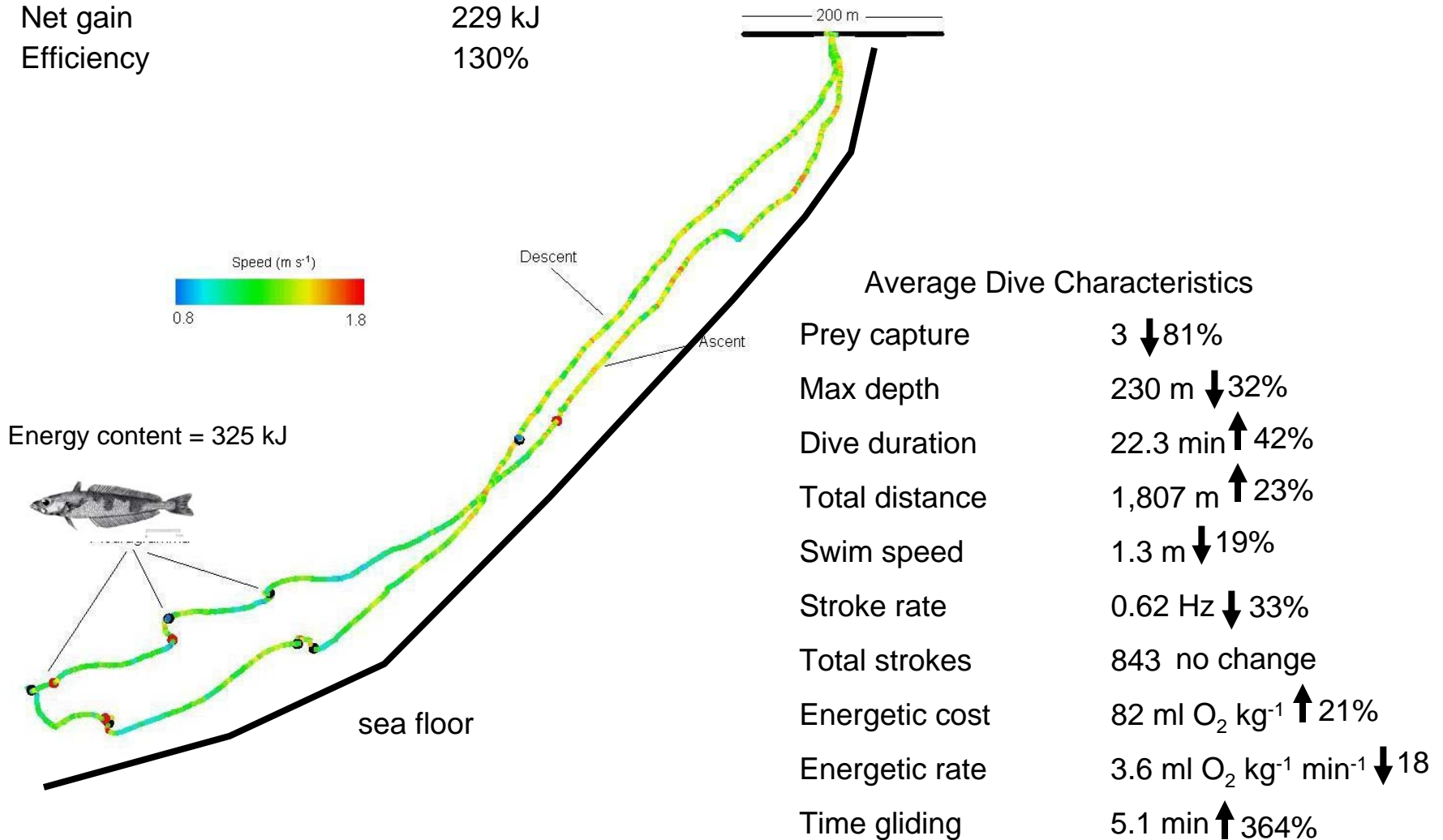


Figure courtesy of Kiersten Madden