Investigating relationships between prey choice and infectious disease in southern sea otters (*Enhydra lutris nereis*)

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Background

- Southern sea otters (*Enhydra lutris nereis*)
  - Keystone predator and sentinel species found along the coast of central California
  - Infectious disease contributes to high mortality rates that hinder population recovery[1]
  - Individualized diet specializations → variation in disease risk[2,3,4]
  - Predominant infectious causes of death (COD) include acanthocephalan peritonitis (AP), protozoal infections, and bacterial infections[1]

→ Is the consumption of certain prey associated with greater odds of mortality due to AP or bacterial infections?

→ What is the risk of consistently consuming a prey item over time, rather than consuming it just prior to death?

Hypotheses and Objectives

- **Aim:** Use 1) prey contents identified in the gastrointestinal (GI) tract of sea otters at necropsy and 2) live sea otter foraging data to examine the role of diet in the development of fatal bacterial infections and AP.
- Hypothesis 1: Bivalve (*Tivela* sp., *Mytilus* sp.) consumption is associated with greater odds of mortality due to bacterial COD.
  - Many bivalves can filter and concentrate pathogenic bacteria → passive disease reservoir for aquatic wildlife[5]

- Hypothesis 2: Sand crab (*Blepharipoda occidentalis* or *Emerita analoga*) consumption is associated with greater odds of mortality due to AP.
  - Sand crabs are an intermediate host for parasites in the phylum Acanthocephala
  - Acanthocephalans ingested via sand crab consumption → GI hemorrhage, chronic inflammation, depleted host energy reserves, secondary bacterial infections[6]

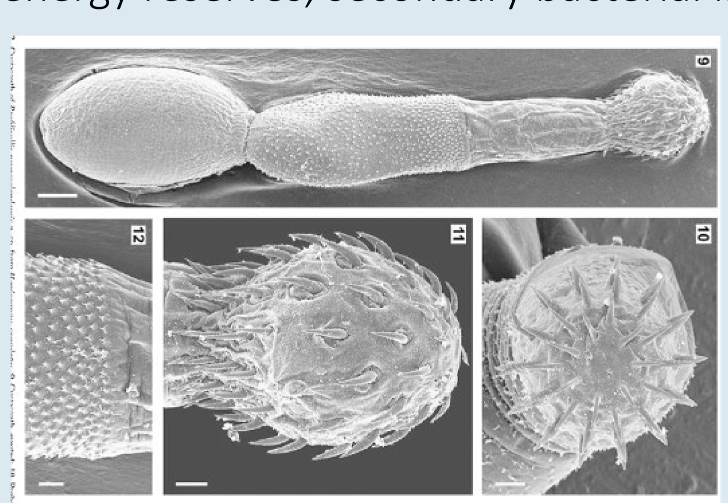


Figure 1. Electron micrograph of an acanthocephalan parasite *Profilicollis* sp. The parasite's spiny proboscis can inflate within the GI tract, damaging the GI mucosa and/or perforating the intestinal wall. Photo: NIH

Methods

- Case-control observational study utilizing:
- **Necropsy data** on 560 stranded otters recovered between 1998 and 2012[1]
  - Primary and contributing COD
  - Stranding date and location
  - GI tract contents (i.e., prey types consumed) (n = 201)

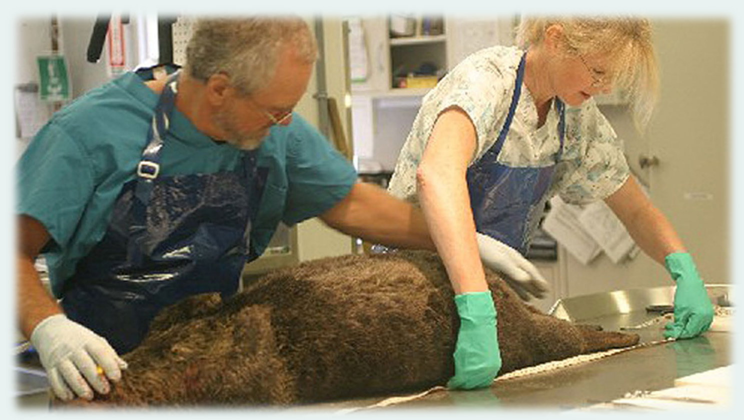


Figure 2. CDFW's Jack Ames and Dr. Melissa Miller collecting morphometric data on a sea otter prior to necropsy. Photo: CDFW.

- Environmental data
  - Habitat at stranding location determined using shoreline classification and seafloor substrate data (USGS CSMP, NOAA ESI)[7,8,9]

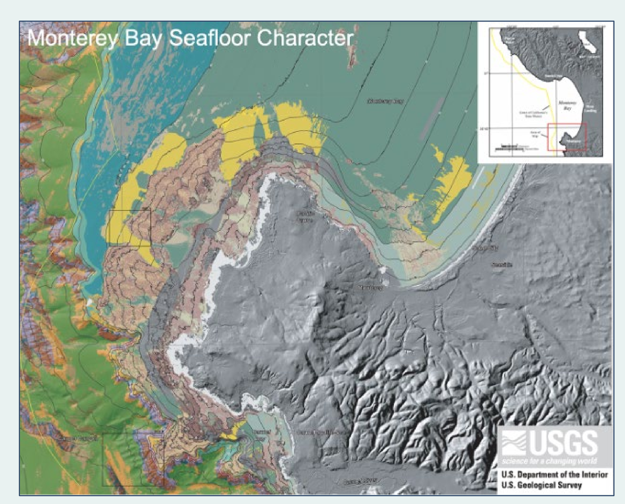


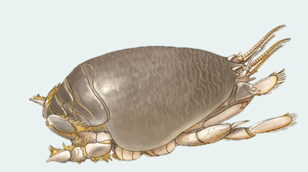
Figure 3. USGS California Seafloor Mapping Project map of Monterey Bay. Colors correspond to seafloor substrate classifications; legend available online.[7]

- Live foraging data
  - Long-term, telemetry-based field studies of free-ranging otters (USGS; n = 31)
  - Observers identify captured prey, estimate its size relative to the otter's paw, and record the number of prey type and size
  - Sea Otter Foraging Analysis (SOFA) algorithm → prey proportions consumed by individual otters[2]
  - Prey contribution to diet ≥10% considered specialization[3,4]
- Statistical analysis (R v4.0.2):
  - Data cleaning and transformation
  - Univariate and bivariate analyses
  - Multivariate logistic regression models:
    - Model building: variables with P < 0.3 in univariate analysis included in forward stepwise selection and backward elimination
    - Model selection using AIC
  - OR and 95% CI quantify strength of associations between risk factors and disease outcomes

Results: Necropsy GI content data

Hypothesis 1:

- Risk factors that increased odds of bacterial COD identified in univariate analyses:
  - Being an **aged adult** (OR=6.7, P=0.004)
  - Being in **poor/fair nutritional condition** (OR=5.9, P<0.001)
  - Stranding in **spring** (OR=3.5, P=0.06) or **winter** (OR=3.6, P=0.07)
- No significant association between bivalves and bacterial COD



Hypothesis 2:

- Final multivariate logistic regression model characterizing AP mortality risk:

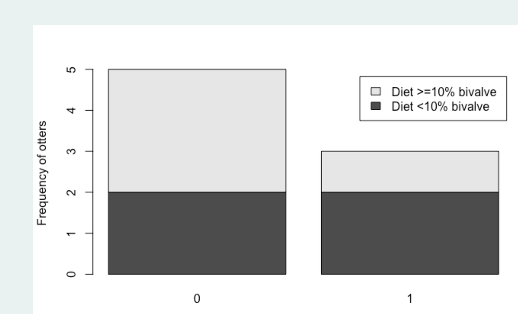
AP ~ sand crabs in GI + nutritional condition + age + sex + fine-medium sand habitat

  - Otters that had recently eaten **sand crabs** were **3.1x** as likely to have died of AP compared to otters that had not (P=0.03)
  - Otters in **poor/fair nutritional condition** were **12x** as likely to have died of AP than those in good/excellent condition (P<0.001)
  - **Subadults** had **2.7x** greater risk of AP mortality compared to adults and aged adults (P=0.04)
  - Being **male** (P=0.08) and **stranding in sandy bottom habitat (P=0.1)** were positively associated with AP mortality (NS)

Preliminary Results: Live foraging data

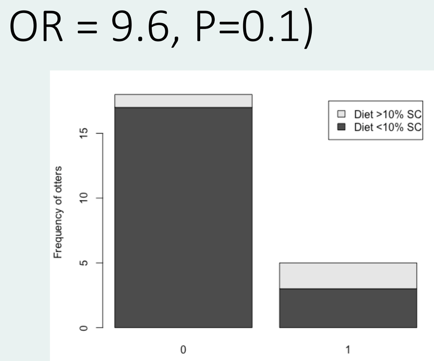
- Otters have individualized diet specializations, with varying contributions of bivalves or crabs to their overall diet[2]
  → Repeat analyses using SOFA output, which describes lifetime diet compositions (USGS, n=31)
- Hypothesis 1:
  - Being a bivalve specialist decreased the odds of fatal bacterial infection, but this was NS (Fisher's exact test: OR = 0.38, P=1)

Bacterial COD	Controls	Cases	Totals
Diet <10% bivalve	2	2	4
Diet ≥10% bivalve	3	1	4
Totals	5	3	8



- Hypothesis 2:
  - Being a sand crab specialist increased the odds of fatal AP, but this was NS (Fisher's exact test: OR = 9.6, P=0.1)

AP COD	Controls	Cases	Totals
Diet <10% sand crab	17	3	20
Diet ≥10% sand crab	1	2	3
Totals	18	5	23



- Increasing sample sizes will improve our ability to explore the infectious disease risks of specific prey preferences

Conclusions & Next Steps

- **Bivalves were not a significant predictor of fatal bacterial infections**
  - Bacterial COD encompasses diverse pathogens that affect multiple organ systems
  - Otters can also acquire pathogenic bacteria directly from the aquatic environment
  - Future research: explore dietary, spatiotemporal, and other risk factors for specific bacterial species
- **Otters that consumed sand crabs just before death were at greater risk of AP mortality**
  - What are the ecological and behavioral drivers of sand crab consumption? Does poor nutrition result from or lead to sand crab consumption? What is the timeline of sand crab consumption → fatal AP?
  - Expanding live foraging and necropsy datasets may yield greater statistical power to measure associations between prey preferences and disease outcomes
  - Future research: Measure and assess different resolutions of parasite density or sand crab consumption to improve precision of risk assessment

Significance

- Understanding risk factors for disease can help us understand mechanisms of infection and prioritize management strategies for this endangered species.
- Identifying high risk behavioral and environmental factors can help us protect otter health in the face of shifting resource availability and population dynamics.

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