Horizontal and vertical migrations of *Dosidicus gigas* in the Gulf of California revealed by electronic tagging

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Why is *Dosidicus* interesting?

**Expanding range**

- Gulf of California, MBARI
  - depth = 1400 m
  - temperature = 3°C
  - oxygen = 10% of surface

**Commercially important**

- FAO 2005: 800,000 m tons
- World’s largest cephalopod fishery
Annual Mean Oxygen (ml/l) at 300 m. Depth

D. gigas range

Guaymas Basin 1970's: CALCOFI

Depth (m)

Oxygen (ml/l)
Dosidicus as predator ….

Prey species tend to be small and associated with the acoustic deep scattering layer.

100,000 metric tons of Dosidicus landed per year in Mexico = 10-20 million squid

Dosidicus and other ommastrephids are thought to follow the DSL to the surface at night for foraging.

Total prey consumption by 15 million squid is about 5 million tons per year…
a major predator

... and important prey

D. gigas paralarva

1mm

other squids

myctophid fishes

Adult Dosidicus

marine mammals
(very) large fishes
Conventional Tag-and-Recapture Studies

1,000 squid were tagged on commercial fishing grounds off Santa Rosalia (Sept.) and Guaymas (April) in 2001.

-- Overall tag return rate of 8%.
-- Growth rate of 1 mm/day.
-- Mass migrations every 6 months.

Markaida et al. 
Fish. Bull.  2005
Electronic Archival Tagging of Dosidicus gigas

Pop-up satellite tags: Horizontal movement and vertical distribution

‘Conventional’ archival tags: Dynamics of vertical movements

Goals:
1) Fall migration routes away from Santa Rosalia -- to Guaymas -- to elsewhere?

2) Vertical migrations and distribution -- diel migration to surface at night? -- more dynamic features?

3) Relationship of vertical migrations to environmental features, especially oxygen concentrations.
Electronic archival tagging of Dosidicus gigas

- Sept 2001
- Oct 2004
- Nov 2005

Map of the Gulf of California showing locations and depths.

Graph showing depth over time for June 2005.
Horizontal movements (Oct-Nov)

Typical rate of ~30 km/day ≈ 0.4 m/s

**Maximum jetting velocity?**
- Jumping out of water: 1.8 m/s (Cole & Gilbert, 1970)
- Chasing lures intended for mahi mahi: 3 m/s

Variable directions:

Nov – Northeast: route to Guaymas via San Pedro Martir basin?
Oct – Southeast to unknown areas or out of Gulf into Pacific?
Pop-up tags consistently show a diel change in vertical distribution -- but there is always a deep nighttime presence.
30 days of archival tag data: Sep/Oct 2002
Typically deep during day
Reliable ascent at sunset
Typically shallow during night
Usually a descent at dawn

Sometimes deep for much of night
Rapid nighttime descents/ascents

Both patterns contribute to deep nighttime component of vertical distribution.
Oxygen profiles
Santa Rosalia
Nov 2005

Mean of 3 Nov pop-up tags

Oxygen concentration (μM)

Depth (m)

Fraction of time

Oxygen concentration (μM)

Oct 2004
Archival tag

Percent of total time

Oxygen concentration (μM)

Day
Night

Mean of 3 Nov pop-up tags

Oxygen concentration (μM)

Fraction of time

Oxygen concentration (μM)

Day
Night

Mean of 3 Nov pop-up tags
Complex vertical migrations

1) Much vertical activity can occur day or night, shallow or deep -- with extreme daily variability.

2) Long periods of time spent in the upper zone of OML at 200-300 m – activity level can be high or low.

Rhythmic activity – foraging?
1) Overall activity levels – day vs. night

Vertical velocity distributions for daytime and nighttime are comparable.

Maximum velocities are similar.
2) Most excursions into OML are brief, but some are very long.

Two distinct processes and purposes?
Behavioral vs. metabolic mechanisms set limits?
Respirometry: Metabolic suppression

Seal tank

Refresh oxygen

Graph showing changes in oxygen concentration over time (min) with a peak oxygen level of 250 µM. The graph also shows respiratory rate changes (mg O₂/kg/hr) at different oxygen levels (µM) ranging from 0 to 200 µM.
Excursions into the OML – two ways of coping with hypoxia?

Frequent rapid dives from shallow nighttime zone to daytime depths – Exit from OML relatively quickly.

Dawn descents to upper zone of OML are followed by inactivity at depth for long periods -- Metabolic suppression?

High activity levels at hypoxic daytime depths – How???
Dosidicus gigas: What does it want with the OML?

Vertical distribution shows that majority of time is spent in upper boundary of OML (< 0.5 ml/l) – mostly during day, but also at night.

Similarity of vertical movements during day and night suggests that foraging goes on during both periods – including much time in upper region of OML.

Long periods of relatively inactivity are also spent in OML – “resting” time to recover from active foraging near surface and to metabolize?

OML provides an enormous environment that is favorable for Dosidicus … and hostile to pelagic predatory fishes.

‘Cannibalism by Humboldt squid’
– Victor, age 6, U.K.
Expanding *Dosidicus* landings and range – does it involve taking advantage of perturbations in OML and mesopelagic ecosystems?

What was status of *Dosidicus* in Gulf of California before 1970?

c. 1965: Parenthetical mention by CA Academy of Science Expedition and by Ray Cannon in popular book on natural history and fishing.

1959: First scientific identification in Gulf – Wormuth (1976)

1943: Strandings on Baja beaches -- interviews with Santa Rosalia fishermen

1940: Not mentioned by Steinbeck and Ricketts -- *Sea of Cortez*

1936: A few mid-sized squid, probably *D. gigas*, viewed by night-lighting in Carmen Basin -- W. Beebe, *Zaca Venture*

1770-1800 – Not mentioned by Jesuit naturalists (del Barco and Clavigero)
Agricultural runoff fuels large phytoplankton blooms in vulnerable areas of the ocean

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Have we assisted *Dosidicus* in its conquest of the Sea of Cortez, or at least the Guaymas basin?
Range expansion in N. America since 2002
Fig. A2-12. Annual mean oxygen (ml/l) at 300 m. depth.

Minimum Value = 0.05  Maximum Value = 7.49  Contour Interval: 0.25

World Ocean Atlas 2001
Ocean Climate Laboratory/NODC
Rapid, deep dives at night tend to occur after excursions into warm near-surface water.
Reduced level of vertical movements following nighttime dives into the OML

Are deep nighttime dives related to recovery from thermal stress?
Fig. A2-12. Annual mean oxygen (ml/l) at 300 m. depth.

Minimum Value = 0.05  
Maximum Value = 7.49  
Contour Interval = 0.25

World Ocean Atlas 2001
Fig. A2-7. Annual mean oxygen (ml/l) at 100 m. depth.

Minimum Value = 0.06  Maximum Value = 7.95  Contour Interval: 0.25

World Ocean Atlas 2001
Ocean Climate Laboratory/NODC
Fig. A2-10. Annual mean oxygen (ml/l) at 200 m depth.

Minimum Value = 0.07  Maximum Value = 7.80  Contour Interval = 0.25

World Ocean Atlas 2001
Ocean Climate Laboratory/NODC
Fig. A2-12. Annual mean oxygen (ml/l) at 300 m. depth.

Minimum Value = 0.05  Maximum Value = 7.49  Contour Interval: 0.25

World Ocean Atlas 2001
Fig. A2-15. Annual mean oxygen (ml/l) at 600 m depth.

Minimum Value = 0.05  Maximum Value = 7.40  Contour Interval = 0.25

World Ocean Atlas 2001
Ocean Climate Laboratory/NODC
Fig. A2-18. Annual mean oxygen (ml/l) at 900 m. depth.

Minimum Value= 0.14                    Maximum Value= 6.51                    Contour Interval: 0.25

World Ocean Atlas 2001
Ocean Climate Laboratory/NODC
Fig. A2-21. Annual mean oxygen (ml/l) at 1200 m. depth.

Minimum Value= 0.33
Maximum Value= 6.55
Contour Interval: 0.20

World Ocean Atlas 2001
Ocean Climate Laboratory/NODC