# Estimated Absorbance Spectra of the Visual Pigments of the North Atlantic Right Whale *(Eubalaena glacialis)*

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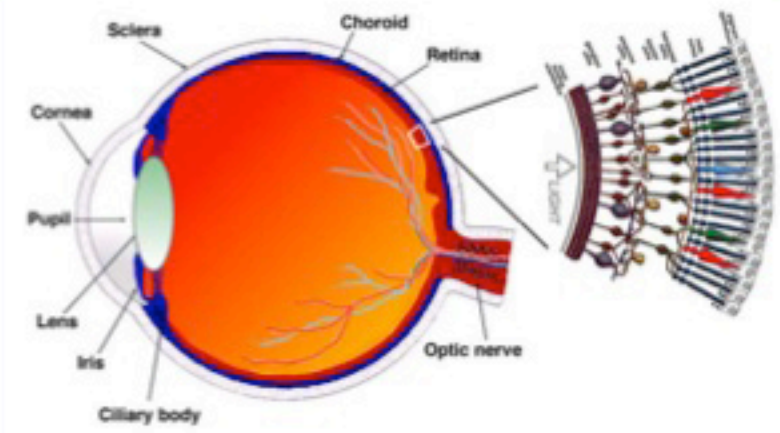
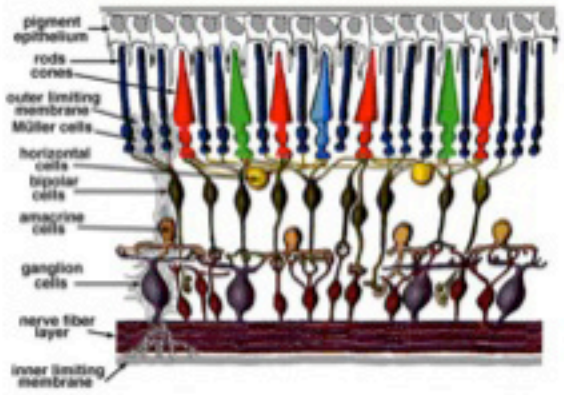
# Outline

- ***The Retina, Cones & Rods and Their Associated Visual Pigments***
- ***Amino Acid Substitutions and Spectral Tuning of Visual Pigments***
- ***Estimated Spectral Sensitivities of E. glacialis Rod and Cone Visual Pigments***
- ***Relationship Between E. glacialis Retinal Sensitivity and C. finmarchicus Spectral Transmission***

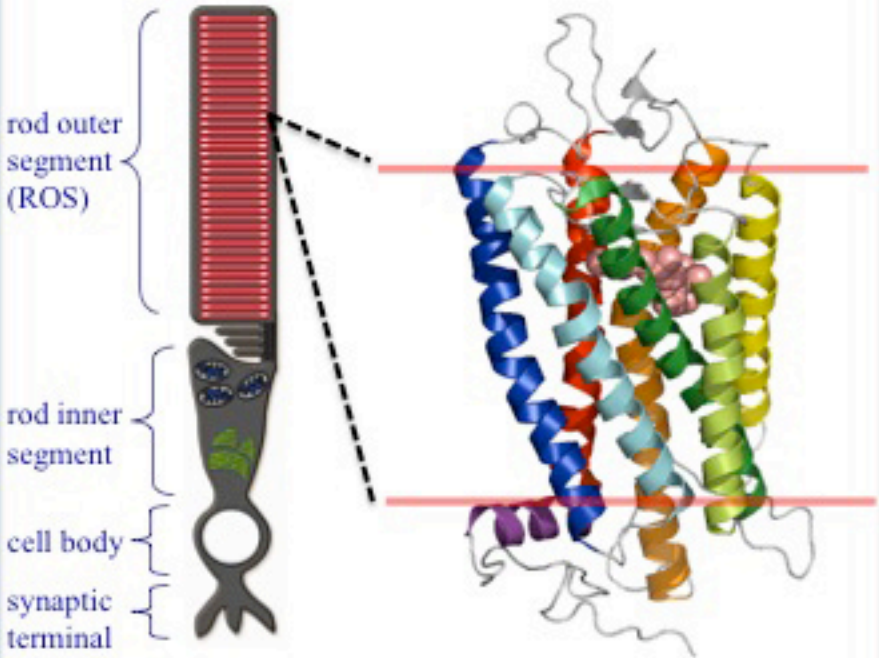
# *The Retina, Cones & Rods and Their Associated Visual Pigments*

# Typical Mammalian Eye

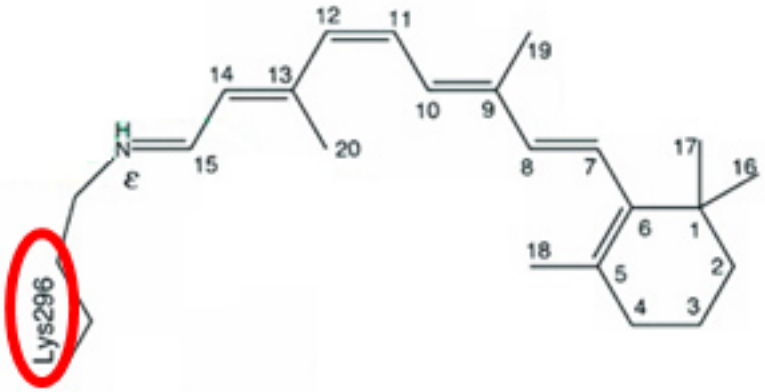


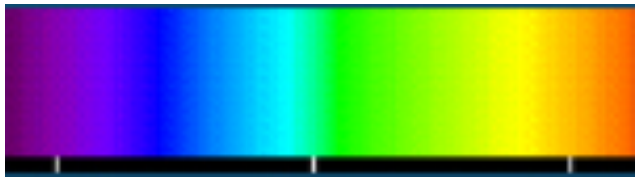




http://www.webvision.med.utah.edu/imageswv/



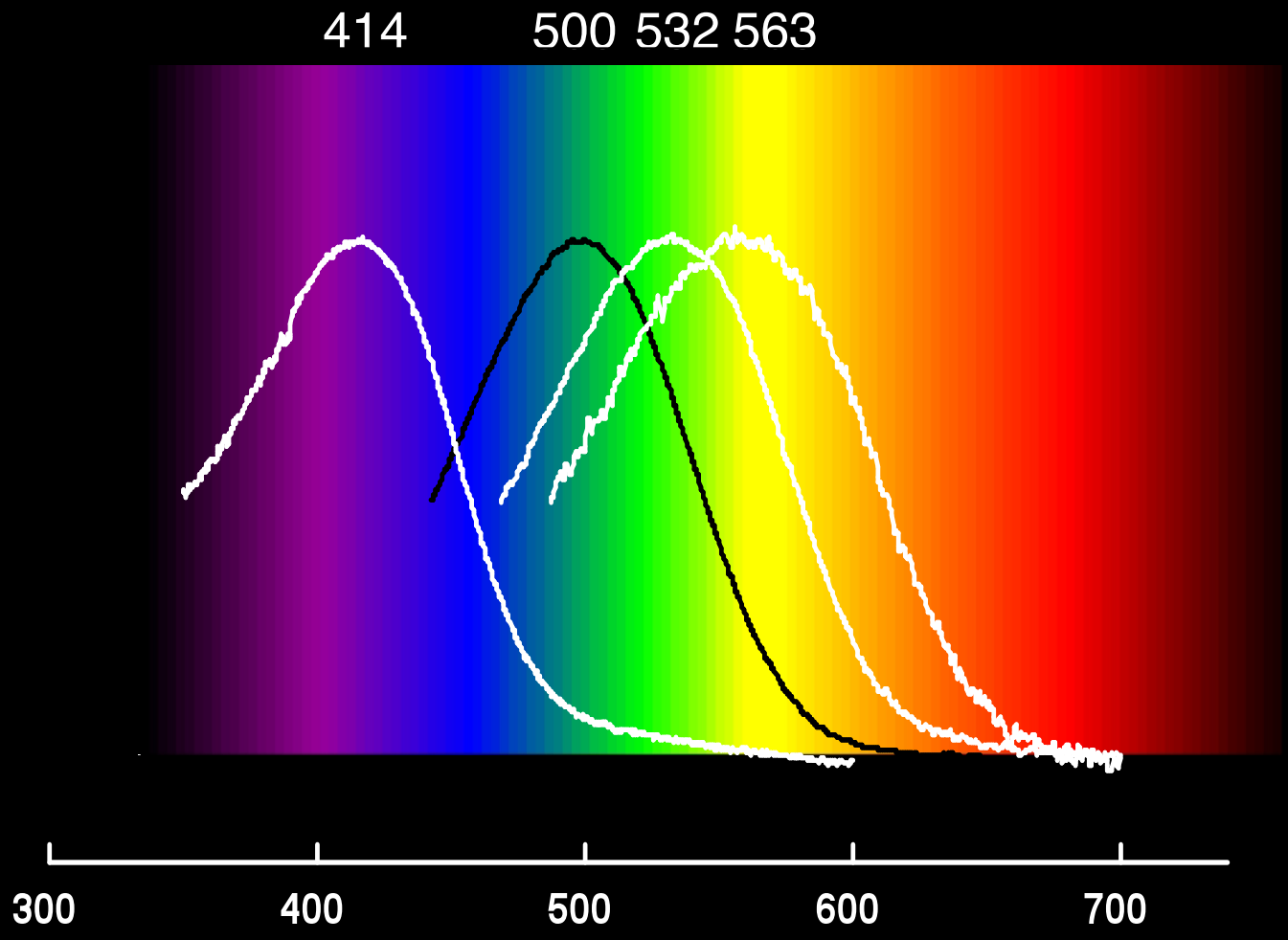
# Moduation of 11-*cis* retinal



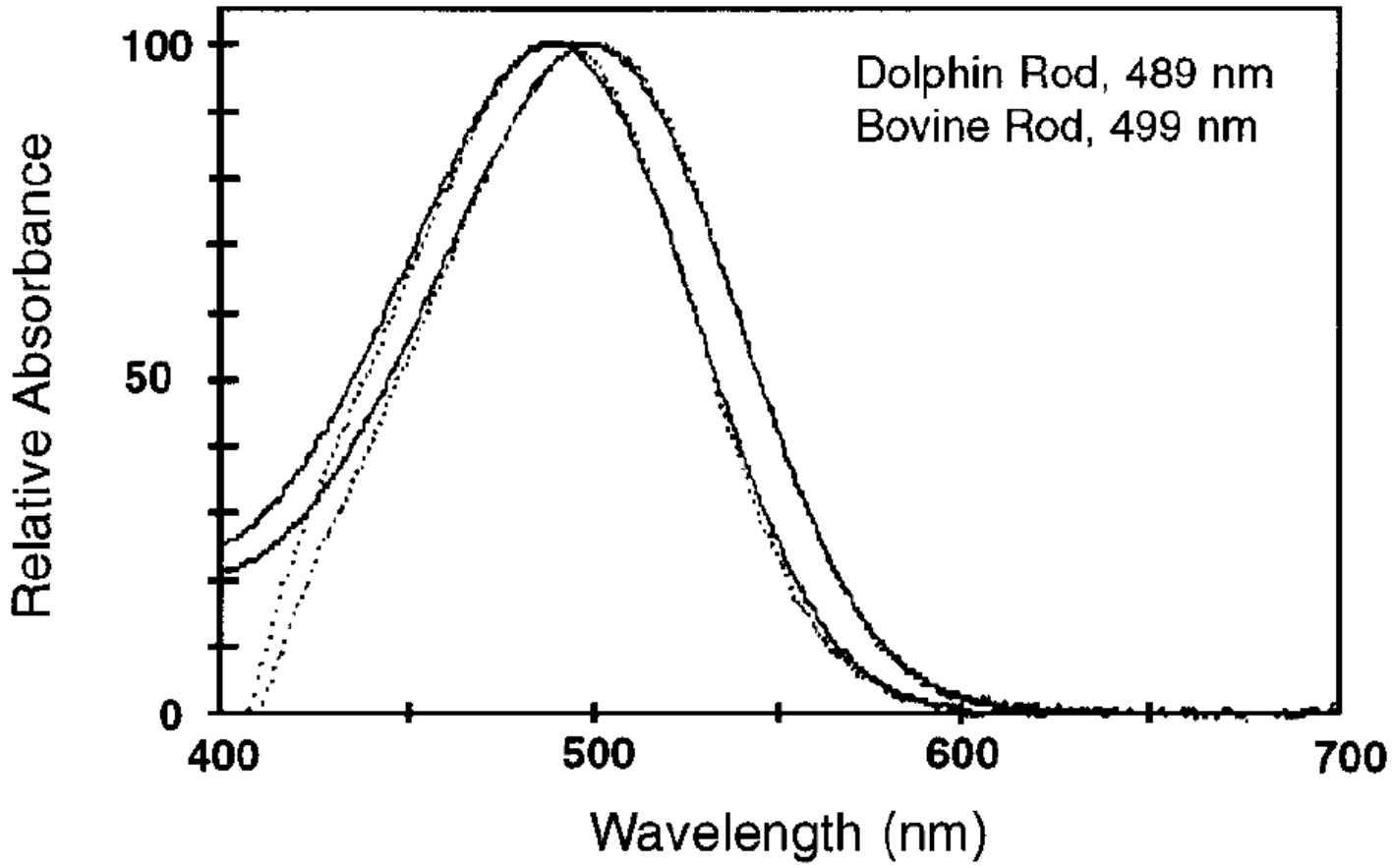
**400 nm** **500 nm** **600 nm**

# *Absorption Maxima of the Human Cone and Rod Visual Pigments*

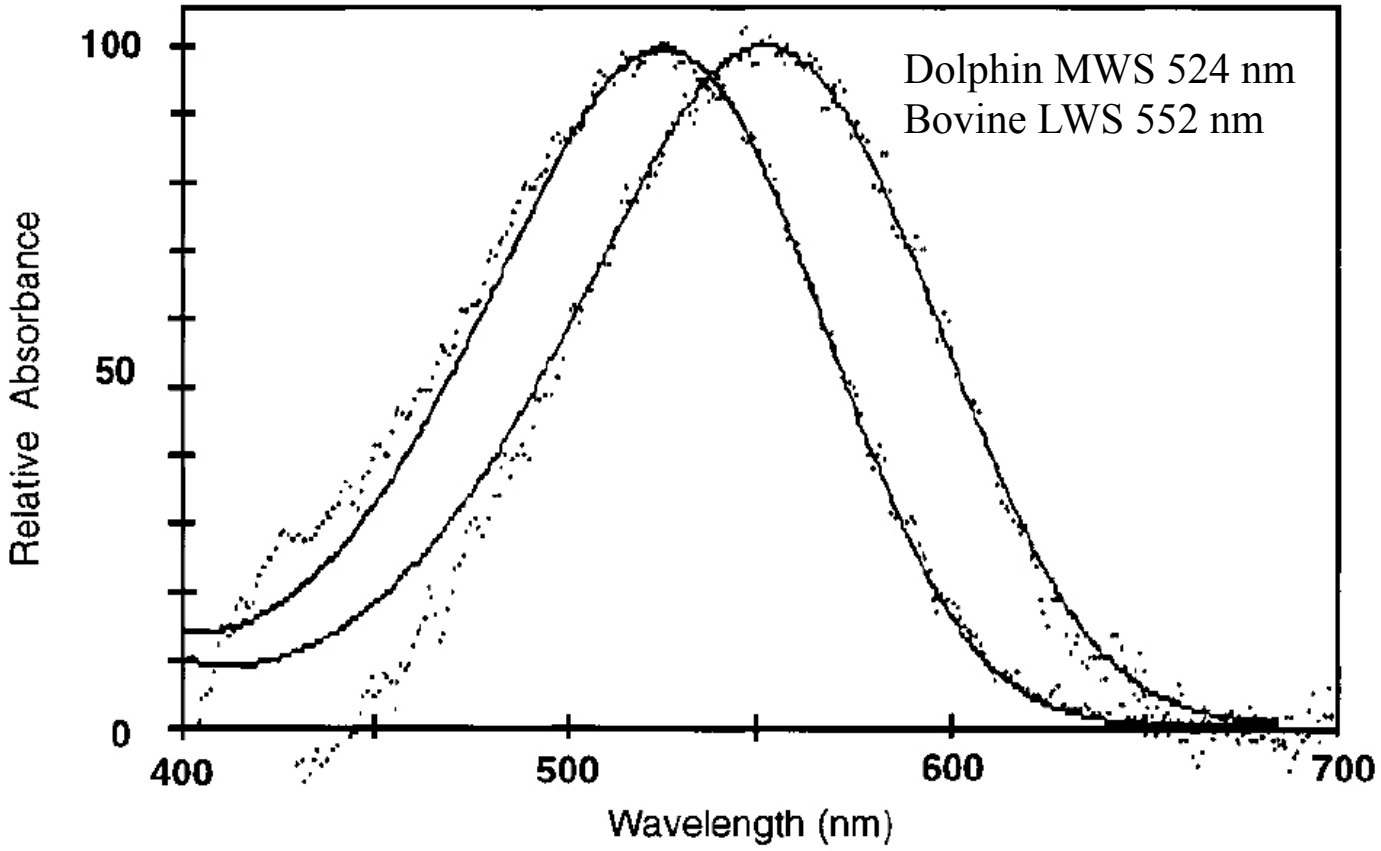


# *Amino Acid Substitutions and Spectral Tuning of Visual Pigments*

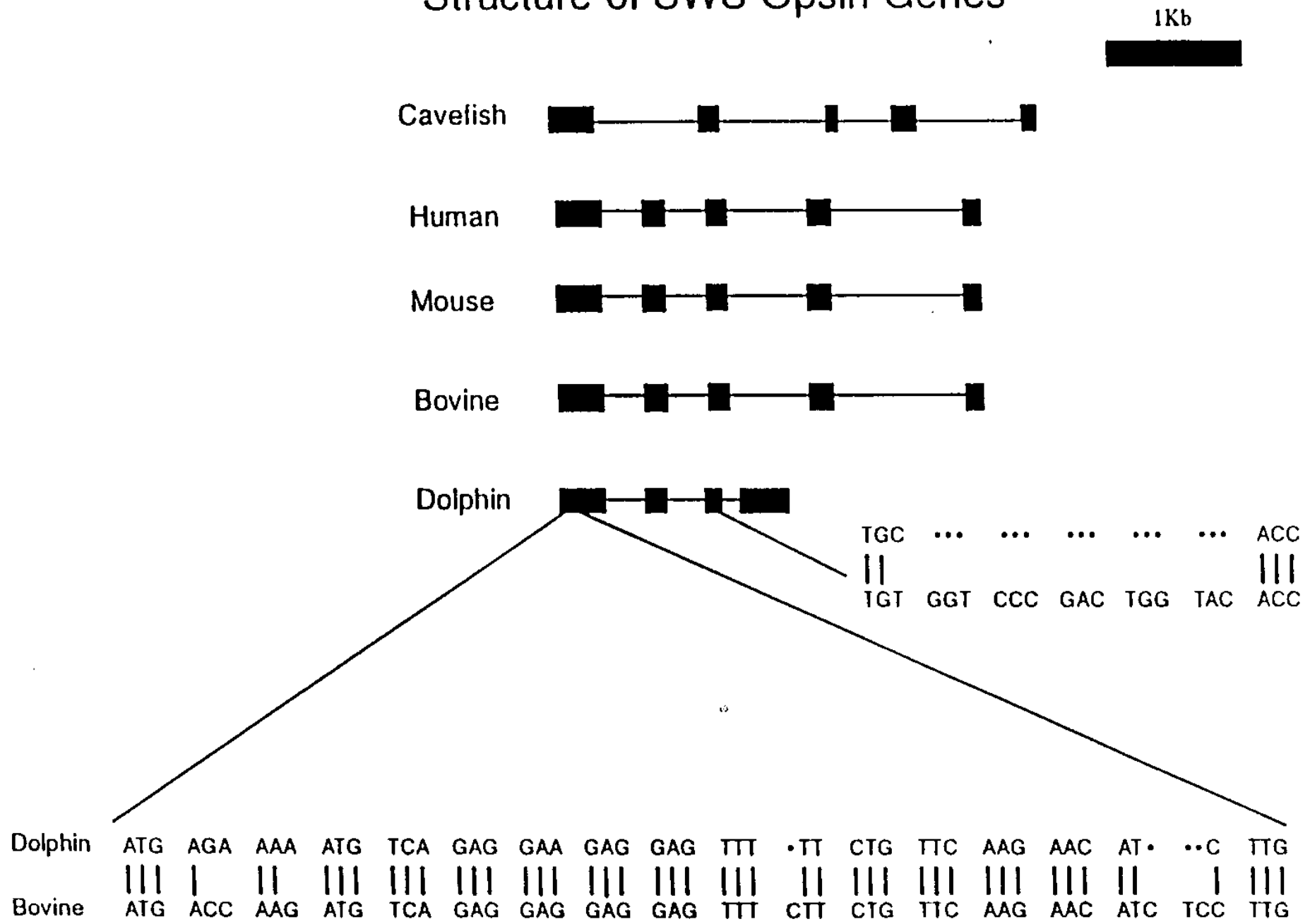
# Dolphin Rhodopsin: Rod Visual Pigment



# Dolphin MWS Cone Visual Pigment



# Structure of SWS Opsin Genes



# Other Marine Mammals Lack Color Vision

**Table 1** Summary of the species examined (Order Carnivora). Taxon names after Rice (1998)

| Family | Genus species | Common name | *N* | Uncorrected "P" distance | | |
|---|---|---|---|---|---|---|
| | | | | Rod opsin | *M*/*L* cone opsin | *S* cone opsin |
| Mustelidae | *Enhydra lutris* | Sea otter | 2 | 0.07684 (AY883931) | 0.08403 (AY884350) | 0.10527 (AY884353) |
| Ursidae | *Ursus maritimus* | Polar bear | 1 | 0.06375 (AY883926) | 0.07587 (AY884345) | 0.10623 (AY884352) |
| Phocidae | *Pagophilus groenlandicus* | Harp seal | – | 0.0659 (AF055318)[a] | 0.0895 (AY228449)[b] | Not examined |
| Phocidae | *Phoca vitulina* | Harbor seal | 2 | 0.06686 (AF055317)[a] | 0.09132 (AF110495)[b] | None found (0.1079)[c] |
| Phocidae | *Pusa hispida* | Ringed seal | 2 | 0.06458 (AY883927) | 0.08652 (AY884346) | None found |
| Phocidae | *Erignathus barbatus* | Bearded seal | 1 | 0.0698 (AY883932) | 0.08399 (AY884351) | None found |
| Phocidae | *Mirounga angustirostris* | Northern elephant seal | 3 | 0.06479 (AY883928) | 0.08922 (AY884347) | None found |
| Phocidae | *Leptonychotes weddellii* | Weddell seal | 2 | 0.06972 (AY883929) | 0.08674 (AY884348) | None found |
| Phocidae | *Hydrurga leptonyx* | Leopard seal | 1 | 0.08133 (AY883930) | 0.08354 (AY884349) | None found |
| Otariidae | *Zalophus californianus* | California sea lion | 2 | 0.06163 (AY883924) | 0.07964 (AY884343) | None found |
| Odobenidae | *Odobenus rosmarus* | Walrus | 2 | 0.0629 (AY883925) | 0.0806 (AY884344) | None found |

Genbank accession numbers are shown in parentheses after each sequence. Uncorrected "P" distances (and Genbank Accession numbers) are shown for each opsin gene as compared to the cat (rod; AJ417432, *M*/*L* cone; AF132040) and cow (*S* cone; U92557)
[a]Genetic data from Fasick and Robinson (2000)
[b]Original data from Genbank
[c]Harbor seal *S* cone opsin data determined from partial nuclear *S* cone opsin (see text)

Levenson et al., J Comp Physiol A (2006) 192: 833–843

# Other Cetaceans also Lack Color Vision

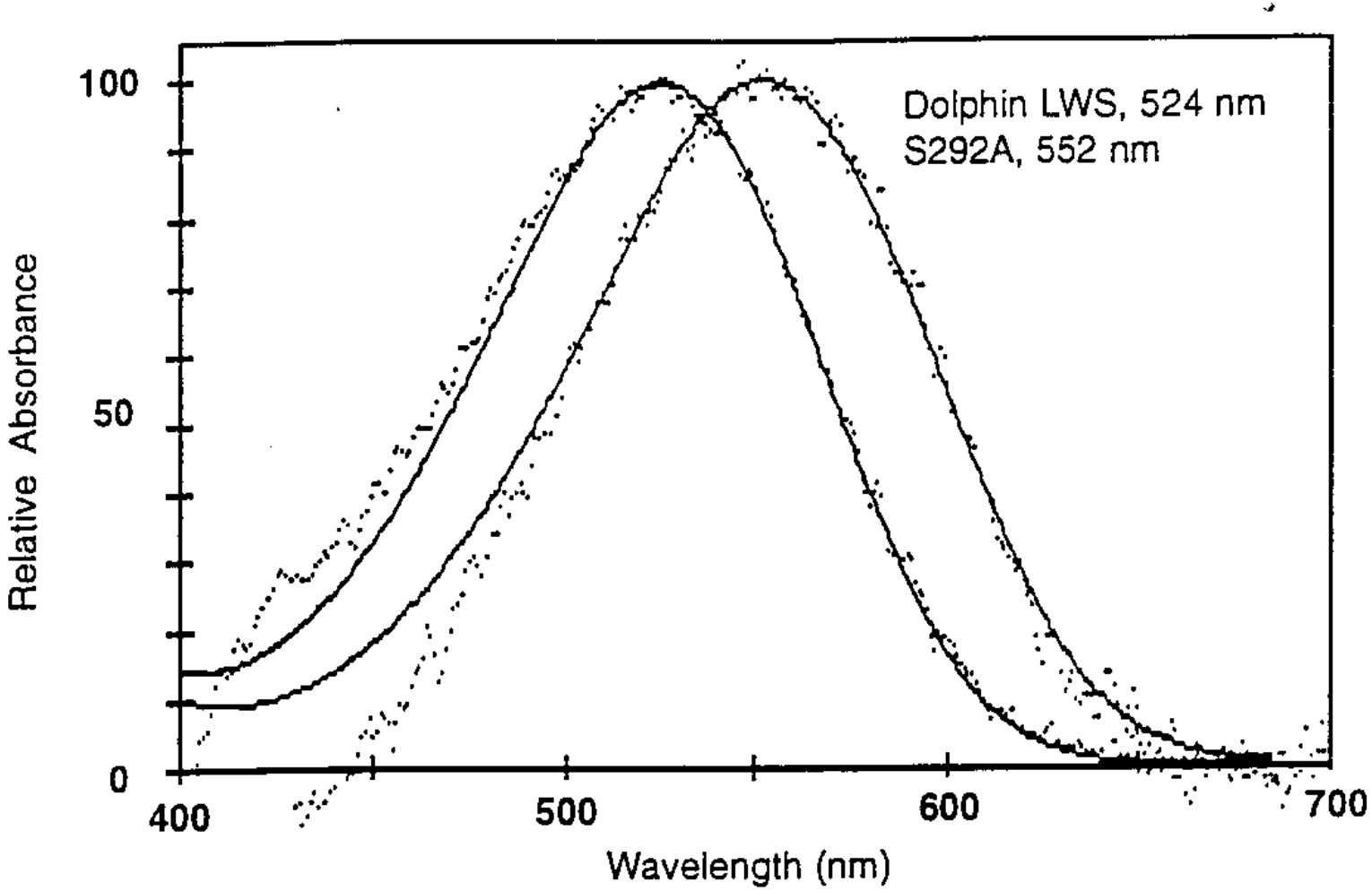
Table 1. Nucleotide identity and non-synonymous substitution proportions for partial (*ca.* 391 bp) hippopotamus and cetacean SWS cone-opsin gene coding-sequences in comparison to the homologous bovine coding sequence (accession number U49760).

| common name | species | nucleotide identity (coding only) | proportion of non-synonymous substitutions (no. of amino acid substitutions/no. of nucleotide substitutions) | indels | apparently functional? | accession number |
|---|---|---|---|---|---|---|
| river hippopotamus | *Hippopotamus amphibius* | 0.936 | 0.16* (4/25) | 0 | yes | AF545497 |
| common minke whale | *Balaenoptera acutorostrata* | 0.938 | 0.50 (12/24) | 1 | no | AF545490 |
| blue whale | *Balaenoptera musculus* | 0.938 | 0.46 (11/24) | 1 | no | AF545484 |
| humpback whale | *Megaptera novaeangliae* | 0.938 | 0.42 (10/24) | 1 | no | AF545494 |
| bowhead whale | *Balaena mysticetus* | 0.933 | 0.54 (14/26) | 1 | no | AF545491 |
| North Atlantic right whale | *Eubalaena glacialis* | 0.930 | 0.56 (15/27) | 1 | no | AF545492 |
| grey whale | *Eschrichtius robustus* | 0.928 | 0.50 (14/28) | 1 | no | AF545493 |
| sperm whale | *Physeter macrocephalus* | 0.918 | 0.44 (14/32) | 0 | no | AF545482 |
| pygmy sperm whale | *Kogia breviceps* | 0.912 | 0.50 (17/34) | 1 | no | AF545486 |
| Indian river dolphin | *Platanista gangetica* | 0.920 | 0.58 (18/31) | 1 | no | AF545487 |
| Sowerby's beaked whale | *Mesoplodon bidens* | 0.929 | 0.48 (13/27) | 2 | no | AF545496 |
| Amazon river dolphin | *Inia geoffrensis* | 0.921 | 0.47 (14/30) | 2 | no | AF545495 |
| franciscana | *Pontoporia blainvillei* | 0.923 | 0.53 (16/30) | 1 | no | AF545483 |
| common bottlenose dophin[a] | *Tursiops truncatus* | 0.909 | 0.57 (20/35) | 3 | no | U92557 |
| beluga whale | *Delphinapterus leucas* | 0.930 | 0.44 (12/27) | 1 | no | AF545485 |
| vaquita | *Phocoena sinus* | 0.936 | 0.44 (11/25) | 1 | no | AF545489 |
| harbour porpoise[a] | *Phocoena phocoena* | 0.928 | 0.46 (13/28) | 1 | no | AF545488 |

[a] Previously identified as lacking SWS cones.
* Significantly different from cetaceans, $p < 0.001$.

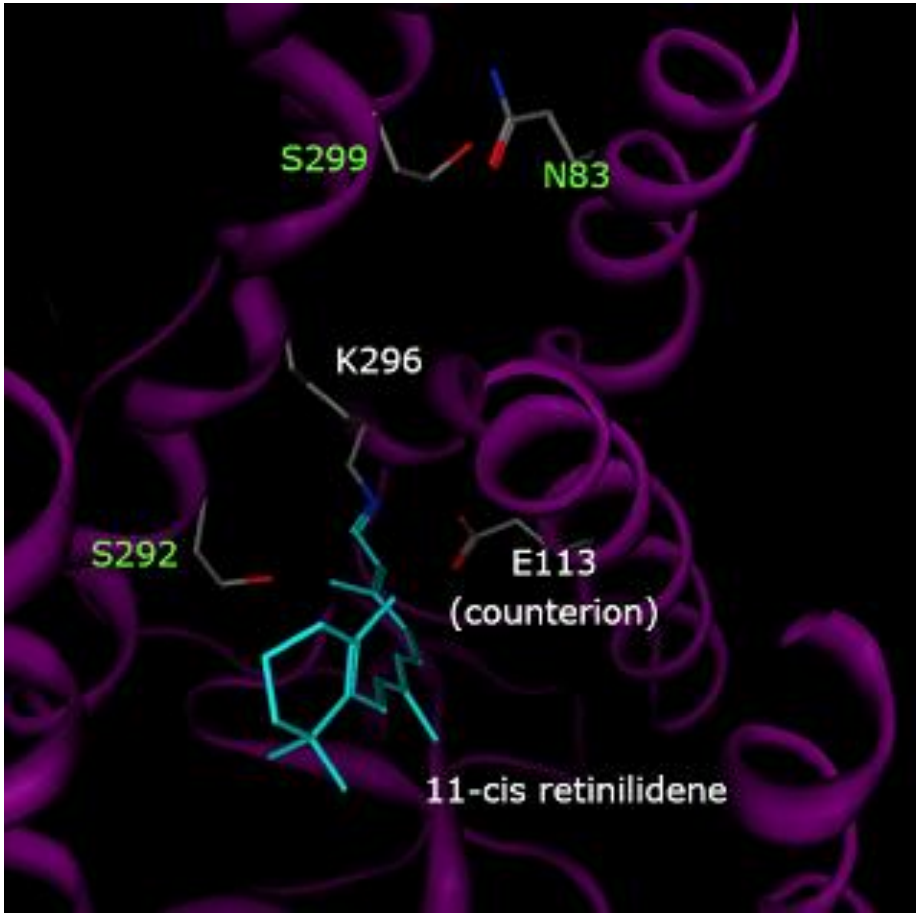
**D. H. Levenson and A. Dizon *Cetacean SWS cone pigments. Proc. R. Soc. Lond.* B (2003) 270, 673–679**

# Spectral Tuning of the Dolphin's Rod and Cone Visual Pigments

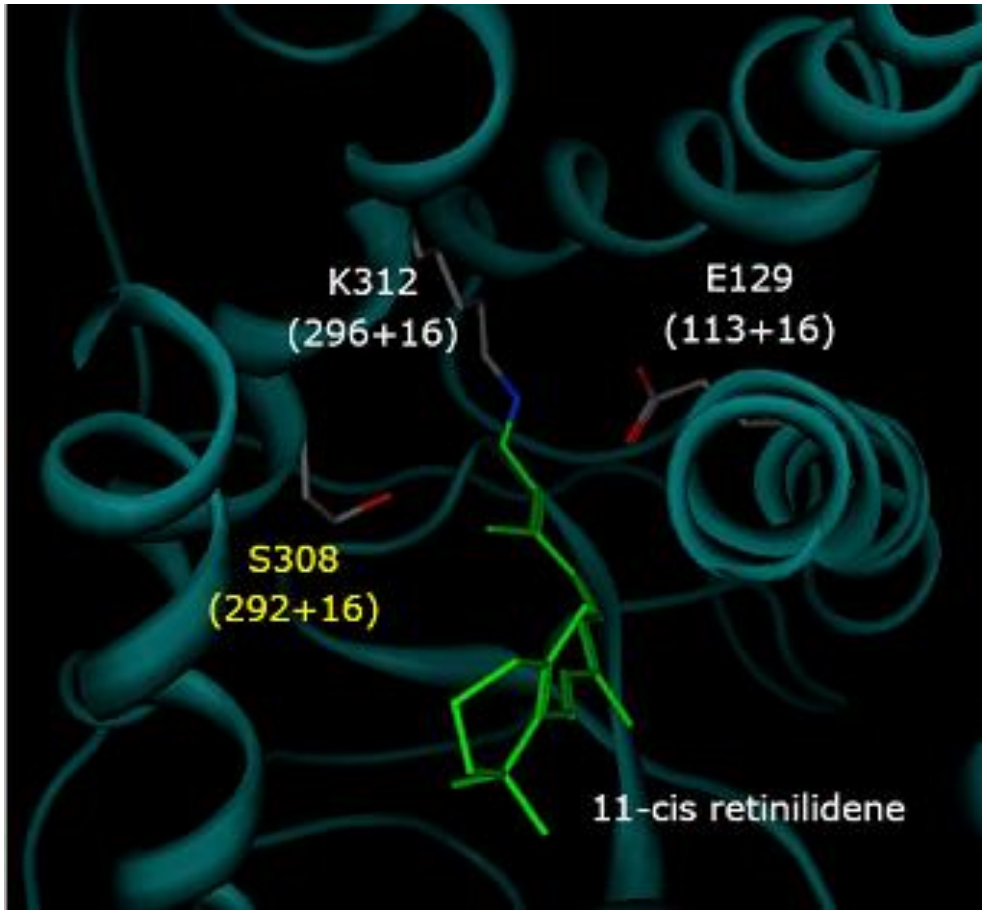


# Models for Cetacean Rod & MWS Cone pigment

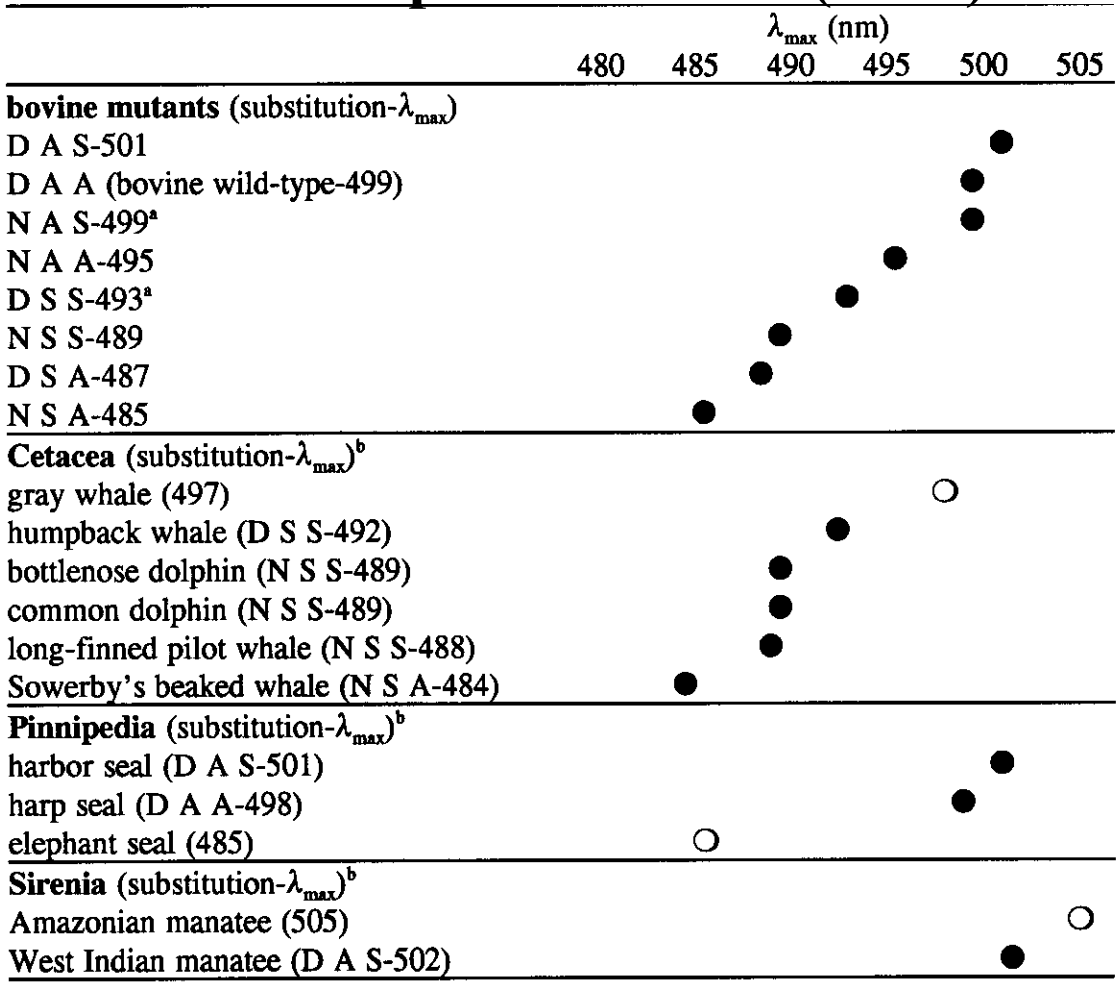
**Model for Dolphin Rod Visual Pigment**




**Model for Dolphin MWS Cone Visual Pigment**



# Comparison of Substitutions at Positions 83, 292 & 299 in Marine Mammal Rod Pigments and Bovine Opsin Mutants and Absorption Maxima (lmax)




[a] Neural network $\lambda_{max}$ prediction.

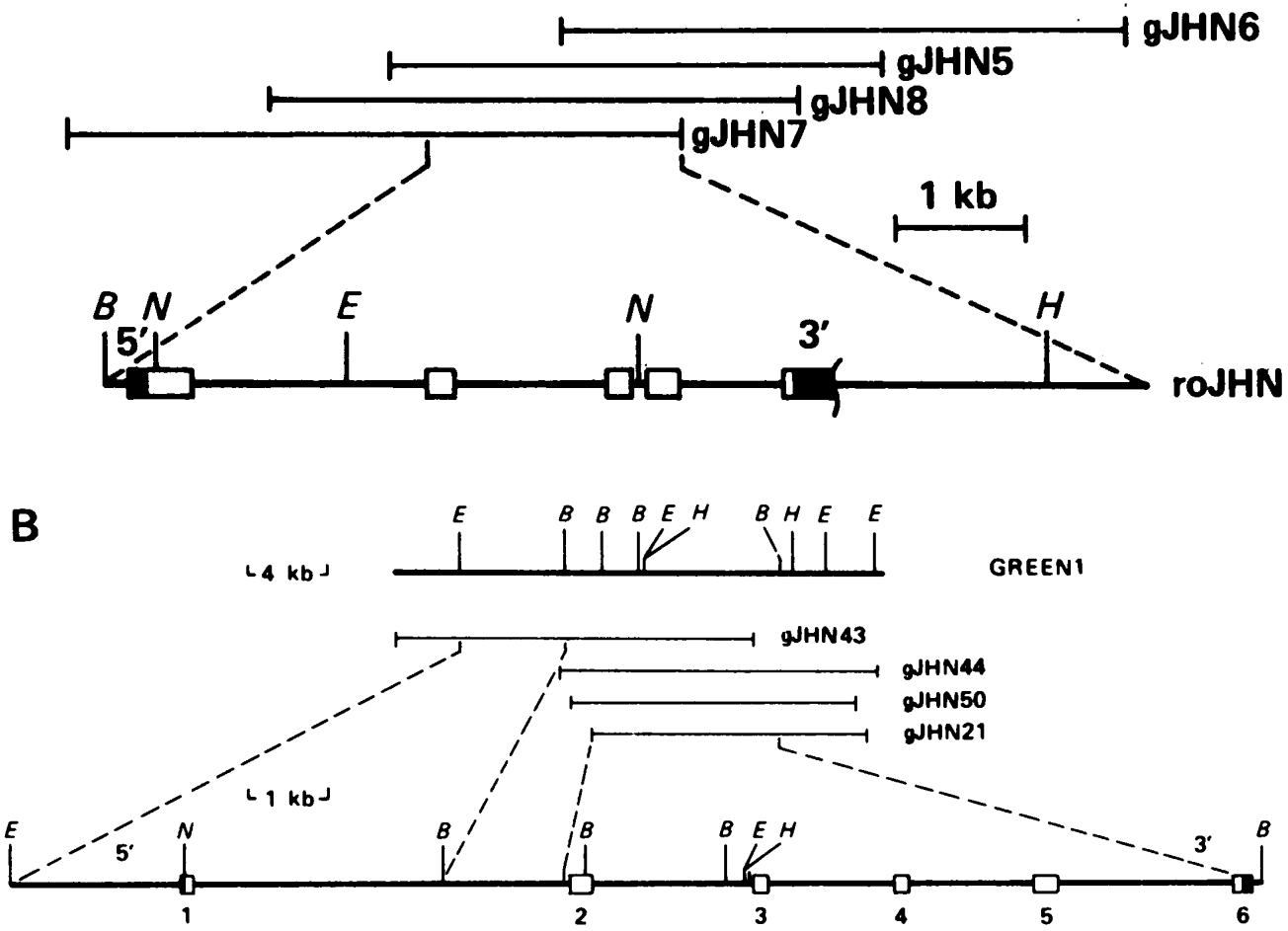
[b] The $\lambda_{max}$ values from species for which sequence data is not available are marked by ○.

# Cetacean Vision

- **The cetacean eye is designed for light capture and not discriminating colors**
- **Photic environment is blue shifted…**
- **And so are the visual pigments**

# *Estimated Spectral Sensitivities of E. glacialis Rod and Cone Visual Pigments*

# Sequence the Exons from the Rod and MWS Cone Opsins




From Nathans & Hogness, 1983 and Nathans, Thomas and Hogness, 1986

## Rod

**Exon 1, TM 2** **83**

***E.glaci*** TVQHKKLRTPLNYILLNLAVA**N**LFMVFGGFTTTLYTSLHAYFVFGP
*B.taur* TVQHKKLRTPLNYILLNLAVA**D**LFMVFGGFTTTLYTSLHGYFVFGP
*D.delp* TVQHKKLRTPLNYILLNLAVA**N**LFMVFGGFTTTLYTSLHAYFVFGP
*G.mela* TVQHKKLRTPLNYIPLNLAVA**N**LFMVFGGFTTTLYTSLHAYFVFGP
*M.bide* TVQHKKLRTPLNYILLNLAVA**N**LFMVLGGFTTTLYTSMHAYFIFGP
*T.trunc* TVQHKKLRTPLNYILLNLAVA**N**LFMVFGGFTTTLYTSLHAYFVFGP

**Exon 4, TM 7** **292** **299**

***E.glaci*** AAAQQQESATTQKAEKEVTRMVIIMVVAFLICWLPYASVAFYIFIHQGSDFGPIFMTIP**A**FFAKSS**S**IYNPVIYIMMNKQ
*B.taur* AAAQQQESATTQKAEKEVTRMVIIMVIAFLICWLPYAGVAFYIFTHQGSDFGPIFMTIP**A**FFAKTS**A**VYNPVIYIMMNKQ
*D.delp* AAAQQQESATTQKAEKEVTRMVIIMVVAFLICWVPYASVAFYIFTHQGSDFGPIFMTIP**S**FFAKSS**S**IYNPVIYIMMNKQ
*G.mela* AAAQQQESATTQKAEKEVTRMVVIMVVAFLICWVPYASVAFYIFTHQGSNFGPIFMTIP**S**FFAKSS**A**IYNPVIYIMMNKQ
*M.bide* AAAQQQESATTQKAEKEVTRMVVIMVVAFLICWVPYASVAFYIFTHQGSNFGPIFMTIP**S**FFAKSS**A**IYNPVIYIMMNKQ
*T.trunc* AAAQQQESATTQKAEKEVTRMVIIMVVAFLICWVPYASVAFYIFTHQGSDFGPIFMTIP**S**FFAKSS**S**IYNPVIYIMMNKQ

## MWS Cone

**Exon 3, TM 4** **180**

***E.glaci*** GITGLWSLAIISWERWMVVCKPFGNVRFDAKLAIAGIAFSWIW**A**AVWTAPPIFGWS…
*B.taur* GITGLWSLAIISWERWMVVCKPFGNVRFDAKLAITGIAFSWIW**A**AVWTAPPIFGWS…
*D.delp* GITGLWSLAIISWERWMVVCKPFGNVRFDAKLAIAGIAFSWIW**A**AVWTAPPIFGWS…
*G.mela* GITGLWSLAIISWERWMVVCKPFGNVRFDAKLAIVGIAFSWIW**A**AVWTAPPIFGWS…
*P.phoc* GITGLWSLAIISWERWMVVCKPFGNVRFDAKLAIAGIAFSWIW**A**AVWTAPPIFGWS…
*T.trunc* GITGLWSLAIISWERWMVVCKPFGNVRFDAKLAIAGIAFSWIW**A**AVWTAPPIFGWS…

**Exon 4** **197**

***E.glaci*** RYWP**H**GLKTSCGPDVFSGSSYPGVQSYMITLMITCCFIPLSVIVLCYLQVWLAIRA
*B.taur* RYWP**H**GLKTSCGPDVFSGSSYPGVQSYMIVLMITCCFIPLSVIILCYLQVWLAIRA
*D.delp* RYWP**H**GLKTSCGPDVFSGSSYPGVQSYMITLMITCCFIPLSVTVLCYLQVWLAIRA
*G.mela* RYWP**H**GLKTSCGPDVFSGSSYPGVQSYMITLMITCCFIPLSVIVLCYLQVWLAIRA
*P.phoc* RYWP**H**GLKTSCGPDVFSGSSYPGVQSYMIALMITCCFIPLSVIVLCYLQVWLAVRA
*T.trunc* RYWP**H**GLKTSCGPDVFSGSSYPGVQSYMITLMITCCFIPLSVIVLCYLQVWLAIRA

**Exon 5, TMs 6 and 7** **277** **285** **308**

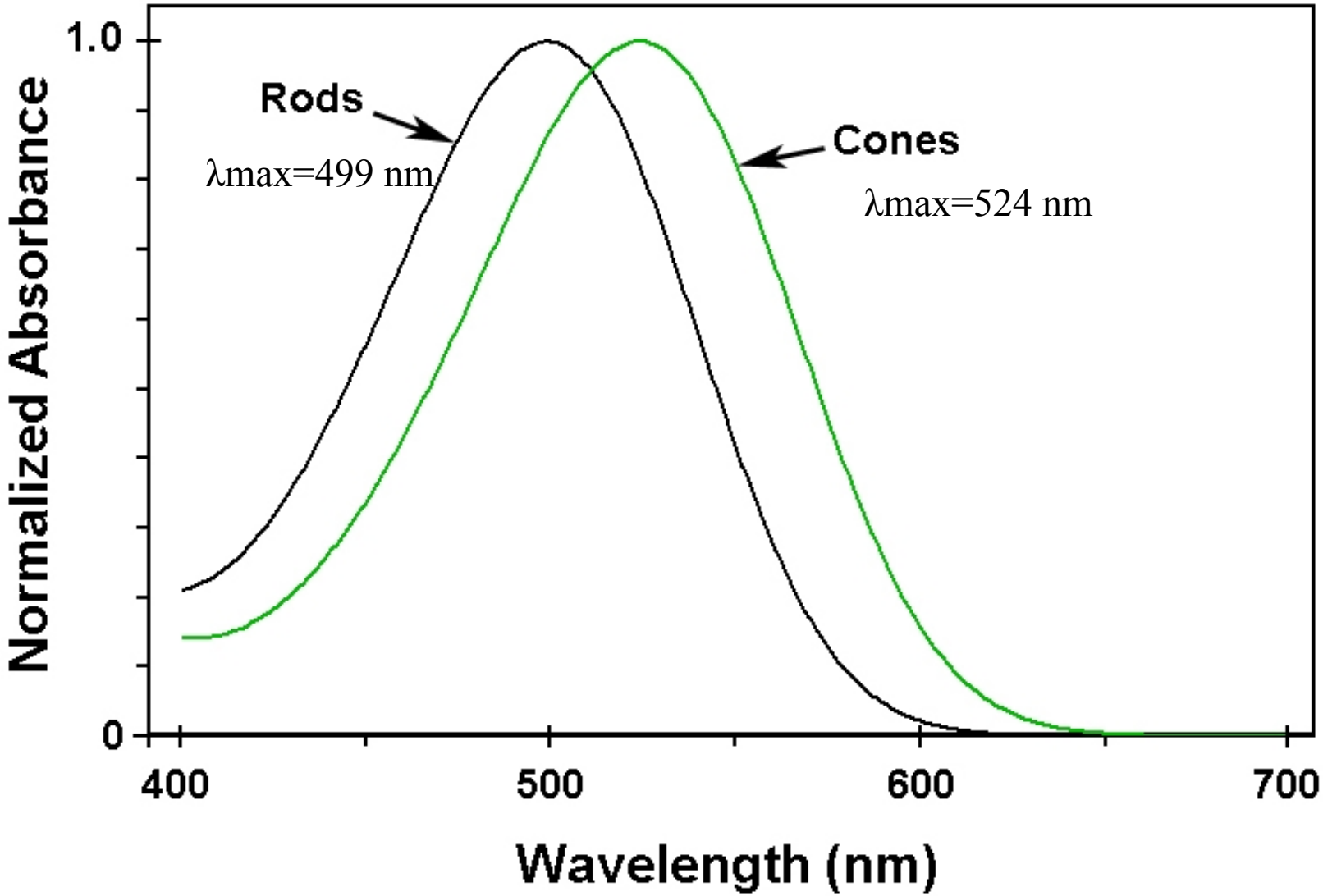
***E.glaci*** VAKQQKESESTQKAEKEVTRIVMVMIFT**Y**CLCWGPY**T**FFACFAAAHPGYAFHPLVAALP**S**YCAKSATIYNPIIYVFMN
*B.taur* VAKQQKESESTQKAEKEVTRMVMVMIFA**Y**CLCWGPY**T**FFACFAAAHPGYAFHPLVAALP**A**YFAKSATIYNPIIYVFMN
*D.delp* VAKQQKESESTRKVEKEVTRMVMVMIFA**Y**CLCWGPY**T**FFACFAAAHPGYAFHPLVAALP**S**YFAKSATIYNPIIYVFMN
*G.mela* VAKQQKESESTRKAEKEVTRMVMVMIFA**Y**CLCWGPY**T**FFACFAAAHPGYAFHPLVAALP**S**YFAKSATIYNPIIYVFMN
*P.phoc* VAKQQKESESTRKAEKEVTRMVMVMIFA**Y**CLCWGPY**T**FFACFAAAHPGYAFHPLVAALP**S**YFAKSATIYNPIIYVFMN
*T.trunc* VAKQQKESESTRKAEKEVTRMVMVMIFA**Y**CLCWGPY**T**FFACFAAAHPGYAFHPLVAALP**S**YFAKSATIYNPIIYVFMN

Table 1: Amino acid substitutions at positions 83, 292 and 299 in marine mammal rod, LWS cone pigments and opsin mutants with resulting absorbance maxima ($\lambda_{max}$)

| | Rod | | | | LWS cone | |
|---|---|---|---|---|---|---|
| | $\lambda_{max}$ (nm) | 83 | 292 | 299 | $\lambda_{max}$ (nm) | 308 |
| **Mutants**[a] | | | | | | |
| *B. taurus* | 501 | D | A | S | 552 (w.t.) | A |
| | 500 (w.t.) | D | A | A | | |
| | 499 | N | A | S | | |
| | 495 | N | A | A | | |
| | 489 | N | S | S | | |
| | 487 | D | S | A | | |
| | 485 | N | S | A | | |
| *T. truncatus* | | | | | 552 | A |
| | | | | | 524 (w.t.) | S |
| **Cetacea** | | | | | | |
| *E. glacialis*[b] | 499 | N | A | S | 524 | S |
| *M. novaeangliae*[a] | 492 | D | S | S | | |
| *T. truncatus*[a] | 488 | N | S | S | | |
| *D. delphis*[a] | 489 | N | S | S | | |
| *G. melas*[a] | 488 | N | S | S | 531[c] | S[c] |
| *M. bidens*[a] | 484 | N | S | A | | |
| *P. phocoena*[a] | | | | | 522[c] | S[c] |

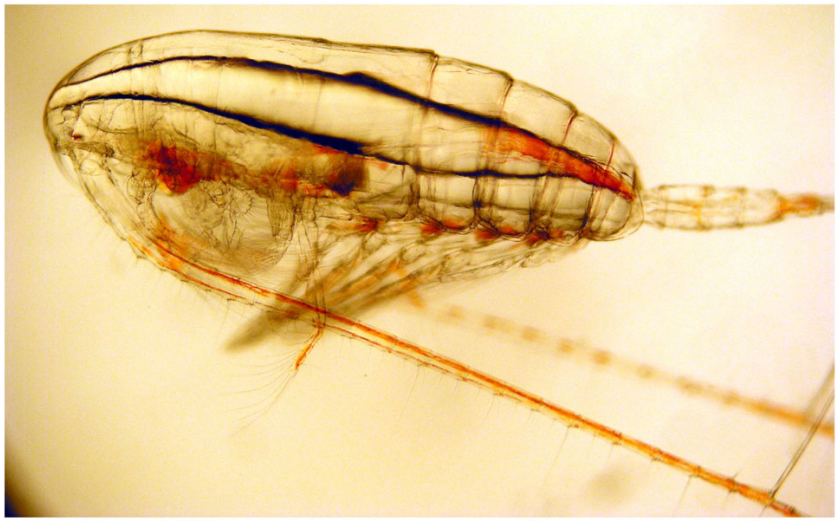
[a]Data from (Fasick & Robinson 1998, Fasick & Robinson 2000)
[b]Predicted from rod and LWS cone mutants
[c]Data from (Newman & Robinson 2005)

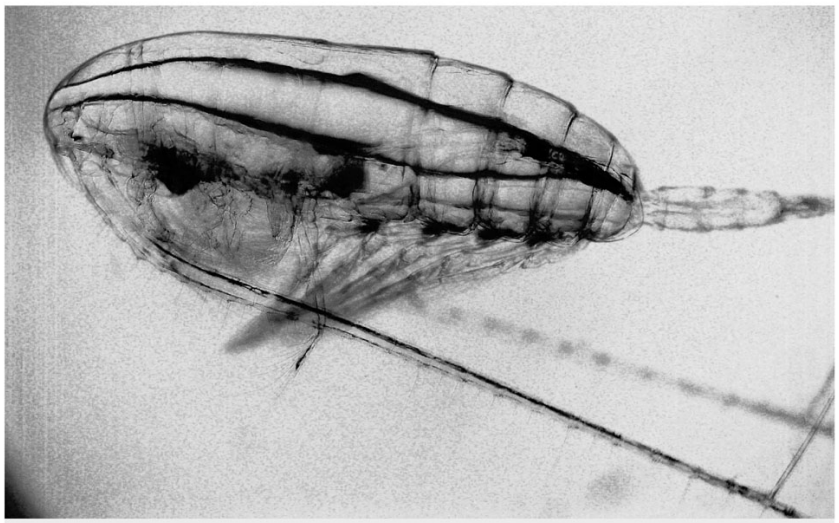
# Estimated Absorbance Spectra of the Visual Pigments of the North Atlantic Right Whale *(Eubalaena glacialis)*

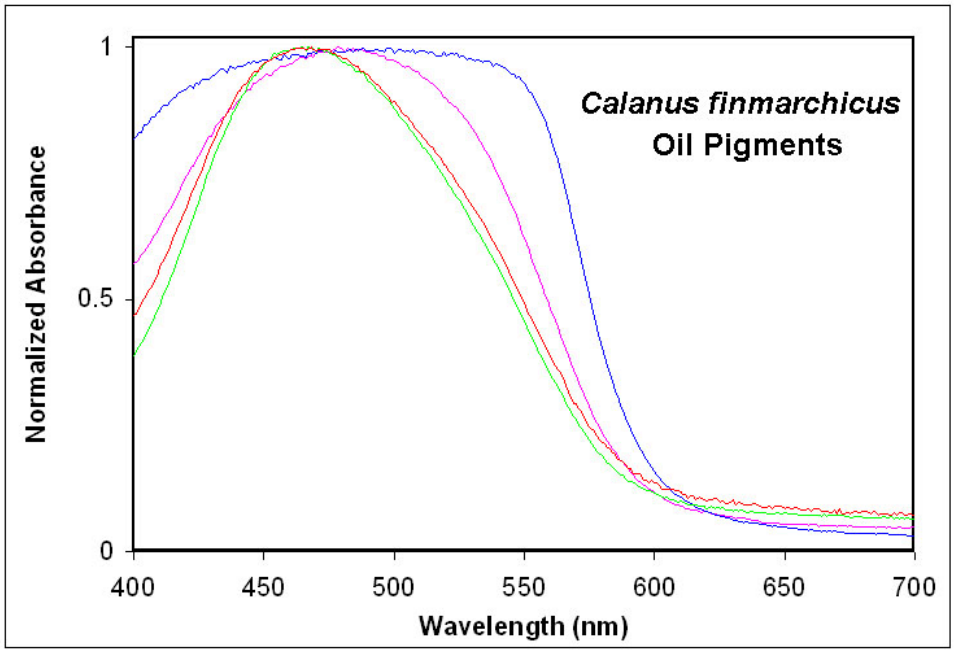


# *Relationship Between E. glacialis Retinal Sensitivity and C. finmarchicus Spectral Transmission*

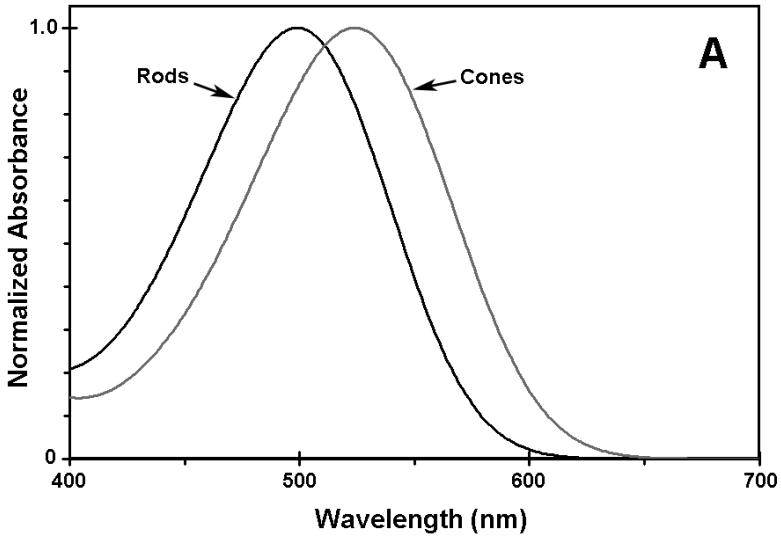
# Absorption Spectra of *C. finmarchicus*

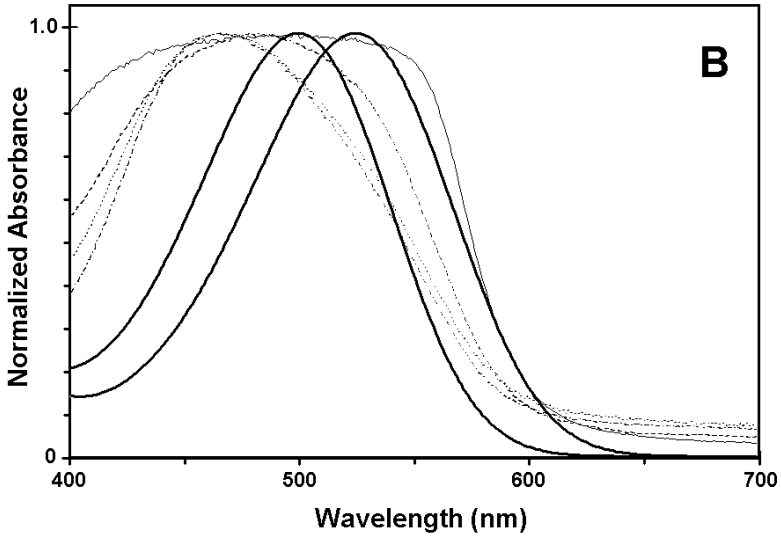






# The Visual Pigments of *E. glacialis* are Matched to the Oil Pigments of *C. finmarchicus*



*Photographs provided by National Geographic's "Kingdom of the Blue Whale"*

# Conclusions

- The absorbance maxima of the *E. glacialis* rod and LWS cone visual pigments are estimated to be 499 nm and 524 nm, respectively

- The right whale appears to possess significant blue-shifting in the MWS cone pigment while the rod pigment retains an absorbance spectrum essentially identical to those of terrestrial mammals

- The spectral placement of these visual pigment enhances the right whale's ability to visually detect the prey species *C. finmarchicus*


Exit
Information
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