

Franklin Erik (Orcid ID: 0000-0002-8660-3085)

For consideration as a *Brief Communication* in the *Journal of Fish Biology*

Word Count: 2871; Figures: 1; Tables: 1

Increased Occurrence of the Rare Golden Colour Morph of Pacific Chub *Kyphosus sandwichensis* in a No-Take Marine Reserve

Erik C. Franklin¹, Madeleine T. Platt^{1,2}, Pelika Andrade³

¹Hawai'i Institute of Marine Biology, School of Ocean and Earth Science and Technology, University of Hawai'i at Manoa, Kane'ohe, HI, 96744, USA

²Dalhousie University, Nova Scotia, Halifax, Canada, B3H 4R2

³University of Hawai'i Sea Grant College Program, Honolulu, HI, 96822, USA

Correspondence

Erik C. Franklin, Hawai'i Institute of Marine Biology, School of Ocean and Earth Science and Technology, University of Hawai'i at Manoa, Kane'ohe, HI, 96744, USA

Email: erik.franklin@hawaii.edu

Funding information

Dalhousie Co-op Program, National Marine Sanctuaries MOA 2005-008/66832

This is the author manuscript accepted for publication and has undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: [10.1111/jfb.15644](https://doi.org/10.1111/jfb.15644)

This article is protected by copyright. All rights reserved.

Abstract

Pacific chub, *Kyphosus sandwicensis*, are typically grey but some individuals display a golden colour morph. We estimated that the frequency of occurrence of the golden morphs increased significantly from 2007 (1.9%) and 2012 (2.6%) to 2017 (5.0%) inside a no-take marine reserve around Nihoa Island in the Northwestern Hawaiian Islands. While sporadic observations of a golden colour morph have been noted for several other marine fish species, we provide a quantitative estimate of changes in the frequency of occurrence of the morph within a wild marine population.

Key Words

golden morph, *Kyphosus sandwicensis*, occurrence, Papahānaumokuākea Marine National Monument, xanthochroism

Fish have six different types of pigment cells known as chromatophores, and the absence of certain ones can result in pigmentation abnormalities (Kelsh, 2004). Ambicoloration, albinism, and xanthochroism (also known as xanthochromism or xanthism) are the three main types of abnormalities that result in different colour morphs that can include partial pigmentation, total lack of pigmentation, and golden-orange pigmentation (Colman, 1972). These color polymorphisms result from genetic expression and response to local cues and chromatophore interactions during development (Dunham and Childers, 1980; Graves and Rosenblatt, 1980; Kelsh, 2004; Henning *et al.*, 2010). The abnormality of a bright yellow or “golden” colour morph is known as having xanthochroism, where individuals lack melanophores, a certain type of chromatophore responsible for black pigment (Colman, 1972).

Several fish species exhibit xanthochroism, though limited research has been done regarding the quantitative occurrence or effects of golden morphs on the ecology of these species. In the tropical Indo-Pacific Ocean, the leopard grouper *Mycteroperca rosacea* (Streets 1877), guineafowl puffer *Arothron meleagris* (Anonymous 1798), bicour fangblenny *Plagiotremus laudandus* (Whitley 1961), longhorn cowfish *Lactoria cornuta* (L. 1758), gold-saddle goatfish *Parupeneus cyclostomus* (Lacepède 1801), orangespotted trevally *Carangoides bajad* (Forsskål 1775), and trumpetfish *Aulostomus chinensis* (L. 1758) are some of the species known to have individuals with uniform gold colouration (Lieske and Myers, 2001; Allen *et al.*, 2003; Randall, 2007; Irigoyen-Arrendondo *et al.*, 2018). In the Atlantic Ocean, the coney grouper *Epinephelus fulvus* (L. 1758) and smooth trunkfish *Lactophrys triqueter* (L. 1758) have also been observed with this type of pigmentation (Robins *et al.*, 1986; Nemtsov *et al.*, 1993; Pattengill-Semmens, 1999). While the presence of xanthochroism has been noted previously for a number of species, most studies examining the effect of gold colour morphs on ecological interactions and evolutionary processes in fish have been limited to the Midas cichlid (*Amphilophus citrinellus* (Günther 1864) and *Amphilophus* spp.), in freshwater lakes of Nicaragua (Henning *et al.*, 2013; Torres-Dowdall *et al.*, 2017).

The Pacific chub *Kyphosus sandwicensis* (Sauvage 1880) displays two colour morphs: the typical phase with a uniformly grey or silver body and the xanthic phase as a uniformly golden yellow body (Figure 1a). We use the name *K. sandwicensis* based on its accepted nomenclature in the World Register of Marine Species (WoRMS Editorial Board, 2023) and common usage within the scientific community in Hawai‘i, while acknowledging that this deviates from

Eschmeyer's Catalog of Fishes (Fricke *et al.*, 2023). For this study, both phases of the *K. sandwicensis* were observed around Nihoa Island, Northwestern Hawaiian Islands within the no-take marine reserve, Papahānaumokuākea Marine National Monument (PMNM). From these observations, we estimated the frequency of the golden colour morph of *K. sandwicensis* for a population around Nihoa Island to evaluate if the proportion of normal to xanthic colour morphs remained stable over a ten-year period.

A diver or snorkeler captured underwater digital still and video images of a large school of *K. sandwicensis* in Nihoa Island, Northwestern Hawaiian Islands during three different periods: July 2007, October 2012, and September 2017. This location is within the PMNM which prohibits recreational and commercial fishing. For each time period, we randomly identified 20 images from a digital still or video frame capture that primarily included the school of *K. sandwicensis*. Each image was treated as a replicate sample of the school to calculate the occurrence of golden morph fish. Using the DotDotGoose software (Ersts, 2023), we digitally placed dots that identified each golden fish and grey fish on all the images (Figure 1b). Then, we summed the counts of golden fish and grey fish in each image. Next, we calculated the percentage frequency of the golden colour morph relative to the total number of fish (i.e., gold and grey fish) in each image. Using the frequency from each image, we calculated a mean frequency of golden fish for each year. We also calculated the median, minimum, and maximum number of golden fish and grey fish from the set of images for each year. We assessed if significant differences existed in the occurrence of the golden colour morph between all pairs of years (i.e., 2007 vs. 2012, 2007 vs. 2017, 2012 vs. 2017) using a generalized linear mixed model with a logit link (function “glmer” in R package *lme4*; Bates et 2015) and a multiple comparison test (function “emmeans”

in R package *emmeans*; Lenth 2023) to accommodate the correlation of repeated observations on the same school of fish within and between years. Observations were treated as a random intercept with mean 0 and variance σ^2 . Model assumptions were verified by plotting and performing a KS test, dispersion test, and outlier test on the residuals, as well as a test for within-group deviation from uniformity and Levene test for homogeneity of variance on the fitted model (R package DHARMA; (Hartig 2022)). Data and software code to replicate the study results are provided as Supplementary Material.

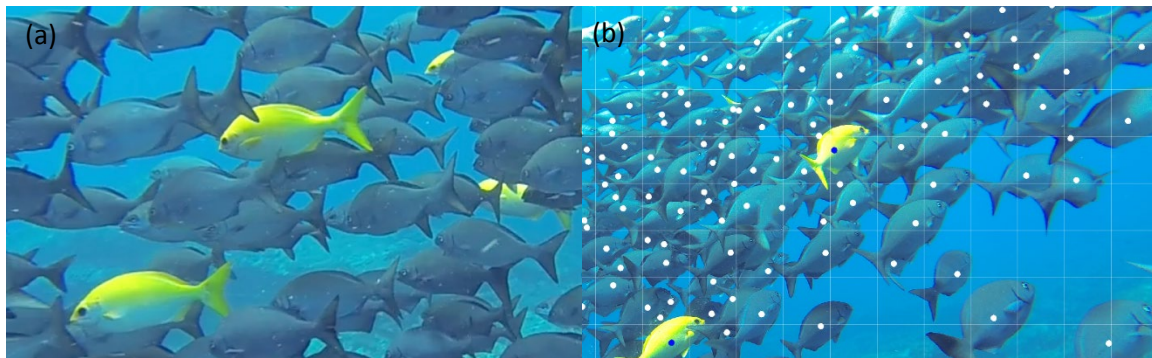


Figure 1. (a) Grey and golden colour morphs of the Pacific chub (*Kyphosus sandwicensis*) (b) Partial image demonstrating digitally placed dots for counts of grey (white dots) and golden (blue dots) morphs of the *K. sandwicensis* using DotDotGoose software (Ersts, 2023). Both images are from a sample of the school around Nihoa Island, Northwestern Hawaiian Islands, during October 2012.

The mean percent frequency of golden colour morph *K. sandwicensis* around Nihoa Island increased across time (1.9% in 2007, 2.6% in 2012, and 5.0% in 2017). Model validation indicated no issues. Golden colour morph frequency differed significantly across years (Wald test $\chi^2= 98.2$ $P < 0.001$) and between 2007 and 2017 (log odds ratio = -1.019, $P < 0.001$) and 2012

and 2017 (log odds ratio = -0.684, $P < 0.001$), but not between 2007 and 2012 (log odds ratio = -0.335, $P = 0.0532$). The median, minimum, and maximum number of golden fish and grey fish per image also increased over the time period (Table 1).

Table 1. Median values and range (with minimum and maximum in parentheses) for numbers of golden and grey Pacific chub *Kyphosus sandwicensis* in 20 images captured each year during 2007, 2012, and 2017 around Nihoa Island, Northwestern Hawaiian Islands.

Year	Golden Pacific chub	Grey Pacific chub
	Median (Min – Max) Counts	Median (Min – Max) Counts
2007	3 (0 – 10)	203 (29 – 456)
2012	7 (2 – 16)	278 (133 – 491)
2017	23 (7 – 58)	444 (197 – 721)

This study presents quantitative estimates of a change in the frequency of occurrence of the golden colour morph for a marine fish. It is unknown if the individuals with the golden colour morphs undergo an ontogenetic color change, similar to the Midas cichlids (Torres-Dowdall *et al.*, 2017), or if they are golden throughout their lives. We observed three total individuals with partially golden colouration in 2012 and 2017, but it was unclear if they were transitioning to a golden phase or had a mixed colouration throughout life. For sailfin mollies *Poecilia latipinna* (Lesueur 1821), F1 progeny from matings between wild-type and xanthic pigmentation were mostly normally pigmented (Angus and Blanchard, 1991). It is possible that the partial

pigmentation results from incomplete dominance in the phenotypic expression of the colour morphs.

While the golden colour morph has been documented for a number of fish species, it is rare for there to be any additional analysis about the prevalence or effects of the morph in a population. The principal exception are the freshwater Midas cichlid species, *Amphilophus* spp., in the crater lakes of Nicaragua. In the Midas cichlid, the gold colour morph is controlled by a single locus caused by a gold-dominant allele (Henning *et al.*, 2010). Colour polymorphism in the Midas cichlid has been found to have an effect on assortative mating and sexual isolation (Elmer *et al.*, 2009). Some results suggest a possible role for the morph in sympatric speciation through sexual selection via colour assortative mating (McKaye, 1980; Elmer *et al.*, 2009). But for cichlids, females are biased toward normal-coloured males while the golden morph modulates aggressive responses from other fish (Barlow, 1998). Similarly, under experimental conditions, both normal and golden colour morphs of the green sunfish *Lepomis cyanellus* (Rafinesque 1819), preferred to mate with normal coloured sunfish (Dunham and Childers, 1980). These results would suggest that a decline, not increase, in the golden phase would be expected in wild populations but the increasing occurrence of the xanthic phase in *K. sandwicensis* suggests a need for further study to identify mechanisms that drive changes in the Nihoa population.

A prior study identified the frequency of the golden morph of a fish across the number of dives but did not report on the occurrence of the morph within the population. On the coral reefs of the Flower Garden Banks, the golden morph of *L. triqueter* was observed on 7.8% of dives over a three-year period with one to three golden fish seen on those dives compared to five to nine

normal coloured *L. triqueter* (Pattengill-Semmens, 1999). At Nihoa Island, we observed that the absolute frequency of the golden colour morph of *K. sandwicensis* increased significantly over ten years from about 2% to 5%. Unfortunately, there is no means of direct comparison between our observations and those of the *L. triqueter* study.

Previous research has speculated that there is a higher susceptibility to predation due to the conspicuous appearance of the golden morph in fish compared to normal colours (Kusche and Meyer, 2013) and the Northwestern Hawaiian Islands have high abundances of marine predators (Friedlander and DeMartini, 2002). However, predation on colour-polymorphic populations can be complicated and situational depending on the predators' visual system and environment (Kusche and Meyer, 2013). The increasing frequency of the golden fish in the *K. sandwicensis* population around Nihoa suggests possible differential reproductive success, recruitment, and survivorship that allowed an increase in the relative occurrence of the rare colour morph.

Remote marine managed areas can provide an important role in the study of coral reef fish populations especially to examine effects from global climate change without the confounding influence of local anthropogenic disturbances (Selkoe *et al.*, 2009). Nihoa Island is a location remote from human populations within the boundaries of the PMNM, a no-take marine reserve which prohibits recreational and commercial fishing. In the main Hawaiian Islands, *K. sandwicensis*, locally called "nenuē", is targeted by fishers. The PMNM protects a high latitude tropical marine environment that allows the study of marine populations under near pristine conditions to provide insights into their ecological structure and dynamics absent the influences of fishing, coastal development, or nearshore pollution. Over the time period of the study, the

maximum number of total *K. sandwicensis* captured in an image increased, which, given the aggregating nature of the school, suggests that the abundance of the population increased. It is unlikely that this natural assemblage would still exist if it was an area open to fishing in the region. Nihoa Island contributes negligible amounts of larvae in oceanographic circulation simulations to other locations in the Northwestern Hawaiian Islands (Wren *et al.*, 2016) but future reef fish surveys of adjacent areas such as Mokumanamana (Necker Island) and Lalo (French Frigate Shoals) should attempt to observe the presence of the golden colour morph in *K. sandwicensis* populations to see if they are spreading across the archipelago.

Author contributions

Erik Franklin: conceptualization, methodology, analysis, resources, writing – original draft, writing – review and editing. Madeleine Platt: analysis, writing – review and editing. Pelika Andrade: resources, writing – review and editing.

Acknowledgements

We thank Paul Jokiel, Craig Musburger, and the crew of the NOAA vessel Hi‘ialakai for field support. Thanks also to the members of the Intertidal partnership including PMNM-NOAA, Nā Maka Onaona, Conservation International, The Nature Conservancy, and various communities. Work was conducted under permit PMNM-2007-029.

Funding Information

ECF was supported by National Marine Sanctuaries MOA 2005-008/66832. MTP was supported by the Dalhousie Co-op Program.

References

- Allen, G., Steene, R., Humann, P. & Deloach, N. (2003). *Reef Fish Identification Tropical Pacific*. Jacksonville, FL: New World Publications, Inc.
- Angus, R. A. & Blanchard, P. D. (1991). Genetic basis of the gold phenotype in sailfin mollies. *The Journal of Heredity* **82**, 425-428.
- Barlow, G. W. (1998). Sexual-selection models for exaggerated traits are useful but constraining. *American Zoologist* **38**, 59-69.
- Bates, D., Maechler, M., Bolker, B., Walker, S. (2015) Fitting linear mixed-effects models using lme4. *J Statistical Software* **67**:1–48
- Colman, J. (1972). Abnormal pigmentation in the sand flounder (note). *New Zealand Journal of Marine and Freshwater Research* **6**, 208-213.
- Dunham, R. A. & Childers, W. F. (1980). Genetics and implications of the golden color morph in green sunfish. *The Progressive Fish-Culturist* **42**, 160-163.
- Elmer, K. R., Lehtonen, T. K. & Meyer, A. (2009). Color assortative mating contributes to sympatric divergence of neotropical cichlid fish. *Evolution* **63**, 2750-2757.
- Ersts, P. J. (2023). DotDotGoose (v1.6).
https://biodiversityinformatics.amnh.org/open_source/dotdotgoose: American Museum of Natural History, Center for Biodiversity and Conservation.
- Fricke, R., Eschmeyer, W. N. & R. van der Laan (eds) (2023). Eschmeyer's Catalog of Fishes: Genera, Species, References.
<http://researcharchive.calacademy.org/research/ichthyology/catalog/fishcatmain.asp>. Electronic version accessed 2023-09-14.

- Friedlander, A. & DeMartini, E. (2002). Contrasts in density, size, and biomass of reef fishes between the northwestern and the main Hawaiian Islands: the effects of fishing down apex predators. *Marine Ecology Progress Series* **230**, 253-264.
- Graves, J. E. & Rosenblatt, R. H. (1980). Genetic Relationship of the Colour Morphs of the Serranid Fish *Hypoplectrus unicolor*. *Evolution* **34**, 240-245.
- Hartig, F. (2022). DHARMA: Residual Diagnostics for Hierarchical (Multi-Level / Mixed) Regression Models. R package version 0.4.6. <https://CRAN.R-project.org/package=DHARMA>
- Henning, F., Jones, J. C., Franchini, P. & Meyer, A. (2013). Transcriptomics of morphological color change in polychromatic Midas cichlids. *BMC Genetics* **14**, 171.
- Henning, F., Renz, A. J., Fukamachi, S. & Meyer, A. (2010). Genetic, Comparative Genomic, and Expression Analyses of the *Mclr* Locus in the Polychromatic Midas Cichlid Fish (Teleostei, Cichlidae *Amphilopus* sp.) Species Group. *Journal of Molecular Evolution* **70**, 405-412.
- Irigoyen-Arrendondo, M. S., Escobar-Sánchez, O., Abitia-Cárdenas, L. A., Moreno-Sánchez, X. G. & Palacios-Salgado, D. S. (2018). Incidence of xanthism in the leopard grouper *Mycteroperca rosacea* (Perciformes: Serranidae) in the Gulf of California. *Marine Biodiversity* **48**, 2255-2258.
- Kelsh, R. N. (2004). Genetics and Evolution of Pigment Patterns in Fish. *Pigment Cell and Melanoma Research* **17**, 326-336.
- Kusche, H. & Meyer, A. (2013). Once cost of being gold: selective predation and implications for the maintenance of the Midas cichlid colour polymorphism (Perciformes: Cichlidae). *Biological Journal of the Linnean Society* **111**, 350-358.
- Lenth, R. V. (2023). emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version 1.8.9. <https://CRAN.R-project.org/package=emmeans>

- Lieske, E. & Myers, R. (2001). *Coral Reef Fishes Indo-Pacific and Caribbean*. London: HarperCollins.
- McKaye, K. R. (1980). Seasonality in habitat selection by the gold colour morph of *Cichlasoma citrinellum* and its relevance to sympatric speciation in the family Cichlidae. *Environmental Biology of Fishes* **5**, 75-78.
- Nemtsov, S., Kajiura, S. & Lompart, C. (1993). Diel Color Phase Changes in the Coney, *Epinephelus fulvus* (Teleostei, Serranidae). *Copeia* **3**, 883-885.
- Pattengill-Semmens, C. V. (1999). Occurrence of a unique color morph in the smooth trunkfish (*Lactophrys triqueter* L.) at the Flower Garden Banks and Stetson Bank, Northwest Gulf of Mexico. *Bulletin of Marine Science* **65**, 587-591.
- Randall, J. E. (2007). *Reef and Shore Fishes of the Hawaiian Islands*. Honolulu, HI, USA: Sea Grant College Program.
- Robins, C., Ray, G. & Douglass, J. (1986). *Atlantic Coast Fishes*. New York: Houghton Mifflin Co.
- Selkoe, K. A., Halpern, B. S., Ebert, C. M., Franklin, E. C., Selig, E. R., Casey, K. S., Bruno, J. & Toonen, R. J. (2009). A map of human impacts to a “pristine” coral reef ecosystem, the Papahānaumokuākea Marine National Monument. *Coral Reefs* **28**, 635-650.
- Torres-Dowdall, J., Golcher-Benavides, J., Machado-Schiaffino, G. & Meyer, A. (2017). The role of rare morph advantage and conspicuousness in the stable gold-dark colour polymorphism of a crater lake Midas cichlid fish. *Journal of Animal Ecology* **86**, 1044-1053.
- Wren, J., Kobayashi, D., Jia, Y. & Toonen, R. (2016). Modeled population connectivity across the Hawaiian Archipelago. *PLoS ONE* **11**, e0167626.

WoRMS Editorial Board (2023). World Register of Marine Species. Available from <https://www.marinespecies.org> at VLIZ. Accessed 2023-06-11. doi:10.14284/170

Figure 1. (a) Grey and golden colour morphs of the Pacific chub (*Kyphosus sandwicensis*) (b) Partial image demonstrating digitally placed dots for counts of grey (white dots) and golden (blue dots) morphs of the *K. sandwicensis* using DotDotGoose software (Ersts, 2023). Both images are from a sample of the school around Nihoa Island, Northwestern Hawaiian Islands, during October 2012.

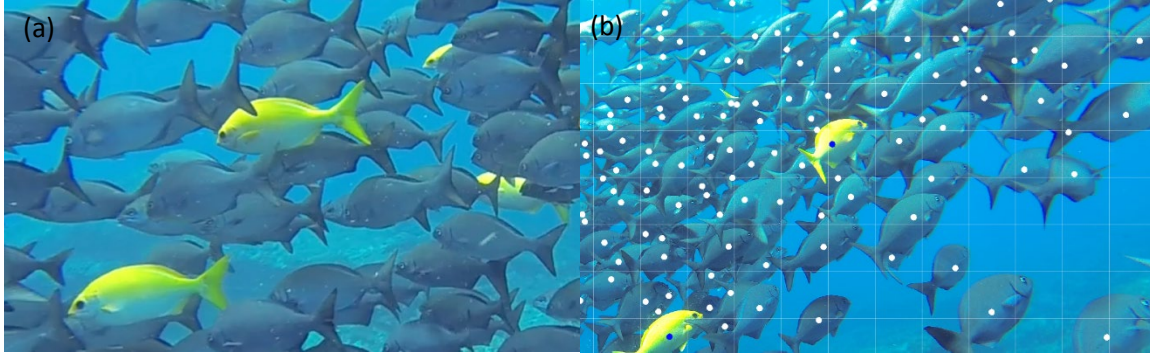


Figure 1. (a) Grey and golden colour morphs of the Pacific chub (*Kyphosus sandwicensis*) (b) Partial image demonstrating digitally placed dots for counts of grey (white dots) and golden (blue dots) morphs of the *K. sandwicensis* using DotDotGoose software (Ersts, 2023). Both images are from a sample of the school around Nihoa Island, Northwestern Hawaiian Islands, during October 2012.

Statement of Significance

The study incorporated surveys of the population of Pacific chub *Kyphosus sandwicensis* within a no-take marine reserve in the Northwestern Hawaiian Islands over a ten-year period. Image-based analyses were used to estimate the frequency of the golden morph versus the typical coloration across time. Our work provides the first documented increase, to our knowledge, in the frequency of occurrence of the golden color morph of a marine fish within a wild population. The golden morph has been previously documented in fish identification books, but quantitative study of the phenomenon is not common in the literature. Rare coloration of fishes is a topic of interest to the fields of ecology, evolution, and aquaculture of ornamental species.

Table 1. Median values and range (with minimum and maximum in parentheses) for numbers of golden and grey Pacific chub *Kyphosus sandwicensis* in 20 images captured each year during 2007, 2012, and 2017 around Nihoa Island, Northwestern Hawaiian Islands.

Year	Golden Pacific chub Median (Min – Max) Counts	Grey Pacific chub Median (Min – Max) Counts
2007	3 (0 – 10)	203 (29 – 456)
2012	7 (2 – 16)	278 (133 – 491)
2017	23 (7 – 58)	444 (197 – 721)