Supplementary Material

**Supplementary Table 1.** Previous studies using maximum likelihood methods on whale sharks.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Location** | **No. individuals** | ***N (a1)*** | **Residency in (a2)** | **Residency out (a3)** | **mortality (a4)** | **% male** | **Reference** |
| Al Lith, Saudi Arabia | 136 | 21.30 | 11.70 | 37.60 | 0.3000 | 47.00 | Cochran et al. 2016 |
| Gulf of Mexico | 1361 | 57.40 | 0.80 | 6.90 | *na* | 61.50 | McKinney et al. 2017 |
| Qatar (Arabian Gulf) | 422 | 123.70 | 28.80 | 62.70 | *na* | 69.00 | Robinson et al. 2016 |
| Oslob (Non-provisioned) | 104 | 5.60 | 22.40 | 94.70 | 0.0030 | 85.00 | Araujo et al. 2014 |
| Maldives (no scars) | 170 | 9.01 | 69.91 | 18.12 | 0.0014 | 90.00 | Harvey-Carroll et al. 2021 |
| Maldives (scarred) | 97 | 13.67 | 46.54 | 28.51 | 0.0004 | 90.00 | Harvey-Carroll et al. 2021 |
| Oslob (Provisioned) | 54 | 13.30 | 44.90 | 22.60 | 0.0003 | 91.00 | Araujo et al. 2014 |
| Qatar (Al Shaheen) | 437 | 115.90 | 17.50 | 37.50 | 0.0004 | 69.00 | Prebble et al. 2018 |
| Southern Leyte | 93 | 15.60 | 27.00 | 42.00 | 0.0007 | 81.00 | Araujo et al. 2017 |
| Honda Bay | 183 | 41.10 | 6.40 | 58.20 | 0.0010 | 96.50 | Araujo et al. 2019 |
| Donsol | 482 | 52.50 | 49.80 | 56.40 | 0.0006 | 88.00 | McCoy et al. 2018 |
| Honduras | 95 | 4.63 | 11.76 | 86.00 | 0.0008 | 65.00 | Fox et al. 2013 |
| St Helena | 273 | 102.15 | 18.90 | 32.82 | 0.0006 | 52.00 | Perry et al. 2020 |
| Bahía de La Paz | 125 | *na* | *na* | *na* | *na* | 75.00 | Ramírez-Macías et al. 2012a |
| Bahía de Los Ángeles | 129 | *na* | *na* | *na* | *na* | 76.00 | Ramírez-Macías et al. 2012b |
| Mozambique | 664 | 50.60 | 9.00 | 29.90 | 0.0006 | 72.00 | Prebble et al. 2018 |
| Tanzania | 139 | 34.78 | 30.63 | 23.90 | 0.0003 | 87.00 | Prebble et al. 2018 |

**Supplementary Table 2**. Results for modified maximum likelihood methods for 25 global whale shark sites as described in Table 2, run on program SOCPROG 2.9 (Whitehead, 2009). QAIC: quasi-Akaike Information Criterion, AIC: Akaike Information Criterion. \*indicates model selection based on AIC, otherwise we followed the QAIC (Whitehead, 2007). Highlighted in **bold** are models with a ΔAIC or ΔQAIC ≤ 2 (Burnham & Anderson, 2002).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **ΔAIC/QAIC** | | | | | | | |
| **Site** | Model A | Model B | Model C | Model D | Model E (Emigration + re-immigration) | Model F | Model G | **Model H** |
| (Closed) | (Closed) | (Emigration and mortality) | (Emigration and mortality) | (Emigration + re-immigration) | (Emigration + re-immigration + mortality) | **(Emigration + re-immigration + mortality)** |
| GAL | 570.6 | 81.3 | 37.9 | 9.2 | 37.9 | 188.7 | 4.1 | **0.0** |
| KOH | 109.2 | 109.2 | 34.2 | 48.5 | 34.2 | **0.9** | **0.0** | **0.9** |
| HOB | 6683.4 | 261.3 | 122.1 | 24.7 | 122.1 | 46.2 | 24.7 | **0.0** |
| HON | 183.8 | 183.8 | 60.0 | 60.0 | 42.9 | **0.0** | 42.9 | **0.0** |
| NIN | 326563.3 | 1621.3 | 500.9 | 192.5 | 500.9 | 163.5 | 192.5 | **0.0** |
| EAS | 74.6 | 74.6 | 6.1 | 55.3 | 6.1 | **0.0** | 6.2 | **0.0** |
| MOZ | 77250.8 | 1055.3 | 152.1 | 150.3 | 152.1 | **0.0** | 150.3 | **0.0** |
| SEY | 91.0 | 91.0 | 22.9 | 70.0 | 22.9 | 26.0 | 6.8 | **0.0** |
| QAT | 16749.3 | 105.4 | 44.3 | 71.5 | 44.3 | 22.4 | 17.7 | **0.0** |
| YUC | 380962.3 | 858.1 | 133.9 | 710.5 | 133.9 | 59.1 | 377.1 | **0.0** |
| SAU | 207.3 | 207.3 | 25.7 | 25.7 | 40.4 | 12.6 | 40.4 | **0.0** |
| THA | 70.6 | 70.6 | 35.1 | 50.5 | 35.1 | 27.4 | **0.5** | **0.0** |
| MAD | 1195.9 | 1195.9 | 224.1 | 419.9 | 224.1 | 81.5 | 419.9 | **0.0** |
| STH | 1901.5 | 23.8 | **1.8** | 2.1 | **1.8** | 5.8 | 2.1 | **0.0** |
| BLP | 833.0 | 833.0 | 151.8 | 81.1 | 151.8 | 129.6 | 81.1 | **0.0** |
| PER\* | 52.3 | 52.3 | **0.0** | **1.9** | **0.0** | 2.9 | **2.0** | 2.9 |
| DON | 18867.1 | 18867.1 | 598.6 | 600.5 | 598.6 | 479.4 | 600.5 | **0.0** |
| PIN | 4701.8 | 4701.8 | 115.0 | 108.4 | 115.0 | **0.0** | 117.0 | **0.0** |
| DJI | 1850.8 | 1850.8 | 205.5 | 4.9 | 205.5 | 98.4 | 202.3 | **0.0** |
| MAF | 2390.0 | 2390.0 | 93.8 | 53.7 | 93.8 | 27.2 | 53.7 | **0.0** |
| SOU\* | 11040.5 | 11040.5 | 269.1 | 269.1 | 267.5 | 207.2 | 271.1 | **0.0** |
| OSL | 129425.4 | 129425.4 | 2641.9 | 2584.2 | 2641.9 | 1660.5 | 2584.2 | **0.0** |
| HAW\* | 1447.6 | 218.0 | 145.2 | 145.2 | 48.3 | 149.2 | 6.7 | **0.0** |
| BLA | 4803.6 | 4803.6 | 607.4 | 607.4 | 593.0 | **0.0** | 2191.5 | **0.0** |
| BEL | 143.3 | 143.3 | 5.7 | 5.7 | 39.9 | 9.7 | **0.0** | 3.6 |

**Supplementary Table 3.** Example of studies reportingindividual whale shark movements between different sites using photographic identification (photo-ID).

|  |  |
| --- | --- |
| **Reference** | **Highlighted photo-ID movements** |
| Andrzejaczek et al. 2016 | Mozambique and Seychelles |
| Araujo et al. 2014 | Within the Philippines, multiple sites |
| Araujo et al. 2017 | Within the Philippines, multiple sites, and Taiwan |
| Araujo et al. 2019 | Within the Philippines, multiple sites, and Indonesia |
| Araujo et al. 2020 | Malaysia and Philippines |
| McKinney et al. 2017 | Gulf of Mexico & the Meso-American Barrier Reef |
| Norman et al. 2017 | Within the Gulf of Mexico and the Meso-American Barrier Reef; Within the Arabian Gulf; Within the Red Sea & Gulf of Aden; Within the eastern coast of Africa; Malaysia & Thailand; Indonesia and Australia; Saudi Arabia and Djibouti |
| Prebble et al. 2018 | Tanzania and Mozambique |
| Ramírez-Macías et al. 2012a | Within the Gulf of California, multiple sites |
| Robinson et al. 2016 | Within the Arabian Sea |

**Supplementary Table 4.** Changes in Lagged Identification Rates (LIR) from 1 day to ~1 year for all sites.

|  |  |  |  |
| --- | --- | --- | --- |
| **Location** | **LIR 1 day** | **LIR ~1 year** | **LIR decline proportion** |
| YUC | 0.0048 | 0.002 | 0.5833 |
| QAT | 0.0086 | 0.0022 | 0.7442 |
| STH | 0.0115 | 0.0027 | 0.7652 |
| SEY | 0.0125 | 0.0033 | 0.736 |
| NIN | 0.0131 | 0.0026 | 0.8015 |
| PER | 0.0137 | 0.0059 | 0.5693 |
| DJI | 0.0142 | 0.005 | 0.6479 |
| BLA | 0.0235 | 0.0052 | 0.7787 |
| MOZ | 0.0241 | 0.0035 | 0.8548 |
| HOB | 0.0257 | 0.0018 | 0.93 |
| DON | 0.0262 | 0.0098 | 0.626 |
| MAF | 0.0263 | 0.0135 | 0.4867 |
| GAL | 0.0303 | 0.0005 | 0.9835 |
| MAD | 0.0354 | 0.0093 | 0.7373 |
| OSL | 0.048 | 0.0263 | 0.4521 |
| BLP | 0.0501 | 0.0159 | 0.6826 |
| EAS | 0.0569 | 0.0122 | 0.7856 |
| PIN | 0.0599 | 0.0163 | 0.7279 |
| SOU | 0.0661 | 0.0302 | 0.5431 |
| SAU | 0.0693 | 0.013 | 0.8124 |
| HAW | 0.1417 | 0.0011 | 0.9922 |
| BEL | 0.1475 | 0.0688 | 0.5336 |
| KOH | 0.1684 | 0.0008 | 0.9952 |
| HON | 0.2289 | 0.0236 | 0.8969 |
| THA | 0.274 | 0.0526 | 0.808 |

**References**

Andrzejaczek, S., Meeuwig, J., Rowat, D., Pierce, S., Davies, T., Fisher, R., et al. (2016). The ecological connectivity of whale shark aggregations in the Indian ocean: a photo-identification approach. R. Soc. Open Sci. 3 (11), 160455. doi:10.1098/rsos.160455

Araujo, G., Lucey, A., Labaja, J., So, C. L., Snow, S., & Ponzo, A. (2014). Population structure and residency patterns of whale sharks, Rhincodon typus, at a provisioning site in Cebu, Philippines. PeerJ, 2, e543.

Araujo, G., Snow, S., So, C. L., Labaja, J., Murray, R., Colucci, A., & Ponzo, A. (2017). Population structure, residency patterns and movements of whale sharks in Southern Leyte, Philippines: results from dedicated photo‐ID and citizen science. Aquatic Conservation: Marine and Freshwater Ecosystems, 27(1), 237-252.

Araujo, G., Agustines, A., Tracey, B., Snow, S., Labaja, J., & Ponzo, A. (2019). Photo-ID and telemetry highlight a global whale shark hotspot in Palawan, Philippines. Scientific reports, 9(1), 1-12.

Araujo, G., Ismail, A. R., McCann, C., McCann, D., Legaspi, C. G., Snow, S., ... & Ponzo, A. (2020). Getting the most out of citizen science for endangered species such as whale shark. Journal of Fish Biology, 96(4), 864-867.

Burnham, K. P., and Anderson, D. R. (2002). Model selection and multimodel inference: A practical information-theoretic approach (New York: Springer-Verlag).

Cochran, J. E. M., Hardenstine, R. S., Braun, C. D., Skomal, G. B., Thorrold, S. R., Xu, K., ... & Berumen, M. L. (2016). Population structure of a whale shark Rhincodon typus aggregation in the Red Sea. Journal of Fish Biology, 89(3), 1570-1582.

Fox, S., Foisy, I., De La Parra Venegas, R., Galván Pastoriza, B. E., Graham, R. T., Hoffmayer, E. R., ... & Pierce, S. J. (2013). Population structure and residency of whale sharks Rhincodon typus at Utila, Bay Islands, Honduras. Journal of fish biology, 83(3), 574-587.

Harvey-Carroll, J., Stewart, J. D., Carroll, D., Mohamed, B., Shameel, I., Zareer, I. H., ... & Rees, R. (2021). The impact of injury on apparent survival of whale sharks (Rhincodon typus) in South Ari Atoll Marine Protected Area, Maldives. Scientific reports, 11(1), 1-15.

McCoy, E., Burce, R., David, D., Aca, E. Q., Hardy, J., Labaja, J., ... & Araujo, G. (2018). Long-term photo-identification reveals the population dynamics and strong site fidelity of adult whale sharks to the coastal waters of Donsol, Philippines. Frontiers in Marine Science, 271.

McKinney, J. A., Hoffmayer, E. R., Holmberg, J., Graham, R. T., Driggers III, W. B., de la Parra-Venegas, R., ... & Dove, A. D. (2017). Long-term assessment of whale shark population demography and connectivity using photo-identification in the Western Atlantic Ocean. PloS one, 12(8), e0180495.

Magson, K., Monacella, E., Scott, C., Buffat, N., Arunrugstichai, S., Chuangcharoendee, M., Pierce, S. J., Holmberg, J., & Araujo, G. (2022). Citizen science reveals the population structure and seasonal presence of whale sharks in the Gulf of Thailand. Journal of Fish Biology, 1– 10. <https://doi.org/10.1111/jfb.15121>

Norman, B. M., Holmberg, J. A., Arzoumanian, Z., Reynolds, S. D., Wilson, R. P., Rob, D., ... & Morgan, D. L. (2017). Undersea constellations: the global biology of an endangered marine megavertebrate further informed through citizen science. BioScience, 67(12), 1029-1043.

Perry, C. T., Clingham, E., Webb, D. H., De la Parra, R., Pierce, S. J., Beard, A., ... & Dove, A. D. (2020). St. Helena: An important reproductive habitat for whale sharks (Rhincodon typus) in the Central South Atlantic. Frontiers in Marine Science, 7, 576343.

Prebble, C. E., Rohner, C. A., Pierce, S. J., Robinson, D. P., Jaidah, M. Y., Bach, S. S., & Trueman, C. N. (2018). Limited latitudinal ranging of juvenile whale sharks in the Western Indian Ocean suggests the existence of regional management units. Marine Ecology Progress Series, 601, 167-183.

Ramírez-Macías, D., Vázquez-Haikin, A., & Vázquez-Juárez, R. (2012a). Whale shark Rhincodon typus populations along the west coast of the Gulf of California and implications for management. Endangered Species Research, 18(2), 115-128.

Ramírez‐Macías, D., Meekan, M., De La Parra‐Venegas, R., Remolina‐Suárez, F., Trigo‐Mendoza, M., & Vázquez‐Juárez, R. (2012b). Patterns in composition, abundance and scarring of whale sharks Rhincodon typus near Holbox Island, Mexico. Journal of fish biology, 80(5), 1401-1416.

Robinson, D. P., Jaidah, M. Y., Bach, S., Lee, K., Jabado, R. W., Rohner, C. A., ... & Pierce, S. J. (2016). Population structure, abundance and movement of whale sharks in the Arabian Gulf and the Gulf of Oman. PLoS one, 11(6), e0158593.

Whitehead, H. A. L. (2007). Selection of models of lagged identification rates and lagged association rates using AIC and QAIC. Communications in Statistics—Simulation and Computation®, 36(6), 1233-1246.

Whitehead, H. (2009). SOCPROG programs: analysing animal social structures. Behavioral Ecology and Sociobiology, 63(5), 765-778.