**Title**

Highly structured populations of deep-sea copepods associated with hydrothermal vents across the Southwest Pacific, despite contrasting life history traits.

**Authors**

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# Abstract

Hydrothermal vents are extreme environments, where abundant communities of copepods with contrasting life history traits co-exist along hydrothermal gradients. Here, we discuss how these traits may contribute to the observed differences in molecular diversity and population genetic structure. Samples were collected from vent locations across the globe including active ridges and back-arc basins and compared to existing deep-sea hydrothermal vent and shallow water data, covering a total of 22 vents and 3 non-vent sites. A total of 806 sequences of mtDNA from the *Cox1* gene were used to reconstruct the phylogeny, haplotypic relationship and demography within vent endemic copepods (Dirivultidae, *Stygiopontius* spp.) and non-vent-endemic copepods (Ameiridae, Miraciidae and Laophontidae). A species complex within *Stygiopontius lauensis* was studied across five pacific back-arc basins at eight hydrothermal vent fields, with cryptic species being restricted to the basins they were sampled from. Copepod populations from the Lau, North Fiji and Woodlark basins are undergoing demographic expansion, possibly linked to an increase in hydrothermal activity in the last 10 kya. Highly structured populations of *Amphiascus* aff. *varians* 2 were also observed from the Lau to the Woodlark basins with populations also undergoing expansion. Less abundant harpacticoids exhibit little to no population structure and stable populations. This study suggests that similarities in genetic structure and demography may arise in vent-associated copepods despite having different life history traits. As structured meta-populations may be at risk of local extinction should major anthropogenic impacts, such as deep-sea mining, occur, we highlight the importance of incorporating a trait-based approach to investigate patterns of genetic connectivity and demography, particularly regarding area-based management tools and environmental management plans.

**S4) Parameters of diversity and demography**

**Table 1: Population genetic diversity measurements for each putative species belonging to the Ameiridae, Miraciidae, and Laophontidae.**

Table includes the number of sequences used for the analysis (Nseq), the number of segregating or polymorphic sites (S), the nucleotide diversity (*π*) ± standard deviation, the number of haplotypes (Nhap), haplotype diversity (*Hd*), *Fst* values, corresponding *p*-values, among-population variation (%) and within-population variation (%).

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Species | Region | Site | Nseq | S | *π* | Nhap | *Hd* | *Fst* | *p-*value | Among-population variation (%) | Within population-variation (%) |
| *Ameira* sp. 4 | ELSC | ABE | 3 | 5 | 0.006 ± 0.005 | 2 | 0.67 | - | - | - | - |
| ELSC | Tu'i Malila | 3 | 15 | 0.02 ± 0.01 | 3 | 1 | - | - | - | - |
| ELSC | Overall | 6 | 17 | 0.01 | 4 | 0.8 | 0 | 1 | 0 | 100 |
| *Ameira* sp. 5 | EPR | Eastwall | 11 | 11 | 0.007 ± 0.004 | 6 | 0.88 | - | - | - | - |
| *Amphiascus* aff. *varians* 1 | ELSC | Tica | 3 | 18 | 0.02 ± 0.02 | 3 | 1 | - | - | - | - |
| EPR | Eastwall | 3 | 60 | 0.07 | 3 | 1 | - | - | - | - |
| EPR | Overall | 6 | 69 | 0.05 | 6 | 1 | 0.01 | 0.49 | 0.85 | 99.15 |
| *Amphiascus* aff. *varians* 2 | ELSC | Kilo Moana | 3 | 0 | 0 | 3 | 0 | - | - | - | - |
| ELSC | ABE | 13 | 4 | 0.004 ± 0.003 | 2 | 0.95 | - | - | - | - |
| ELSC | Tow Cam | 2 | 0 | 0 | 1 | 0 | - | **-** | - | - |
| Woodlark | La Scala | 7 | 9 | 0.005 ± 0.003 | 4 | 0.7 | - | **-** | - | - |
| ELSC+Woodlark | Overall | 25 | 27 | 0.01 ± 0.007 | 14 | 0.93 | **0.72** | **0** | 72.4 | 27.6 |
| *Sarsamphiascus* sp. 1 | ELSC | Tu'i Malila | 4 | 1 | 0.5 | 2 | 0.5 | - | - | - | - |
| *Bathylaophonte pacifica* | EPR | Tica | 1 | - | - | - | - | - | - | - | - |
| EPR | Eastwall | 2 | 1 | 0.002 ± 0.003 | 2 | 1 | - | - | - | - |
| EPR | Overall | 3 | 1 | 0.001 ± 0.002 | 2 | 0.67 | 0 | 1 | - | - |

**Table 2: Demographic parameters calculated for each putative species belonging to the Ameiridae, Miraciidae, and Laophontidae.**

The demographic histories of the *Cox1* gene in species of the genera *Ameira*, *Amphiascus,* *Sarsamphiascus* and *Bathylaophonte*. Parameters calculated: number of sequences (Nseq), number of haplotypes (Nhap), Tajima’s *D*, Fu’s *Fs*, Sum of Squared Deviation (SSD) and the raggedness index (*rg*).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Species | Region | Site | Nseq | Nhap | Tajima's *D* | Fu's *Fs* | SSD | *rg* |
| *Ameira* sp. 4 | ELSC | ABE | 3 | 2 | 0 | 2.34(*p* = 0.81) | 0.39(*p* = 0.4) | 1(*p* = 0.72) |
| ELSC | Tu'i Malila | 3 | 3 | 0 | 1.14(*p* = 0.45) | - | - |
| ELSC | Overall | 6 | 4 | 0 | 1.75(*p* = 0.63) | 0.18(*p =* 0.05) | 0.09(*p* = 0.09) |
| *Ameira* sp. 5 | EPR | Eastwall | 12 | 6 | 0.25(*p* = 0.63) | 0.57(*p* = 0.6) | 0.06(*p* = **0.02**) | 0.19(*p* = **0.03**) |
| *Amphiascus* aff. *varians* 1 | EPR | Tica | 3 | 3 | 0(*p* = 1) | 1.33(*p* = 0.50) | 0.273(*p* = 0.3) | 0.67(*p* = 0.77) |
| EPR | Eastwall | 3 | 3 | 0(*p* = 1) | 2.57(*p* = 0.55) | - | - |
| EPR | Overall | 6 | 6 | 0(*p* = 1) | 1.95(*p* = 0.52) | 0.09(*p* = 0.28) | 0.17(*p* = 0.34) |
| *Amphiascus* aff. *varians* 2 | ELSC | Kilo Moana | 3 | 3 | - | - | - | - |
| ELSC | ABE | 13 | 2 | -1.4(*p* = 0.07) | -0.7(*p* = 0.32) | 0.02(*p* = 0.34) | 0.05(*p* = 0.44) |
| ELSC | Tow Cam | 2 | 1 | - | - | - | - |
| Woodlark | La Scala | 7 | 4 | -1.59(*p* = **0.03**) | *0.35(*p = 0.56) | 0.09(*p* = 0.53) | 0.18(*p* = 0.65) |
| ELSC + Woodlark | Overall | 25 | 14 | 0.19(*p* = 0.61) | -1.54(*p* = 0.29) | 0.02(*p* = 0.2) | 0.02(*p* = 0.49) |
| *Sarsamphiascus* sp. 1 | ELSC | Tu'i Malila | 4 | 2 | -0.61(*p* = 0.38) | 0.17(*p* = 0.34) | 0.02(*p* = 0.00) | 0.25(*p* = 1.00) |
| *Bathylaophonte* *pacifica* | EPR | Tica | 1 | - | - | - | - | - |
| EPR | Eastwall | 2 | 2 | - | - | - | - |
| EPR | Overall | 3 | 2 | - | - | - | - |

**Table 3: Population genetic diversity measurements for each putative species belonging to the Dirivlutidae (*Stygiopontius*).**

Population genetic diversity measurements for each *Stygiopontius* species Including the number of sequences used for the analysis (Nseq), the number of segregating or polymorphic sites (S), the nucleotide diversity (*π*) ± standard deviation, the number of haplotypes (Nhap), haplotype diversity (*Hd*), *Fst* values, corresponding p-values, among-population variation (%) and within-population variation (%).

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Species | Region | Site | NSeq | S | *π* | NHap | *Hd* | *Fst* | *p*-value | Among-population variation (%) | Within-population variation (%) |
| *Stygiopontius brevispina* | ELSC | Kilo Moana | 8 | 7 | 0.003 ± 0.002 | 5 | 0.81 | - | - | - | - |
| ELSC | ABE | 1 | - | - | - | - | - | **-** | - | - |
| ELSC | Tu'i Malila | 26 | 13 | 0.004 ± 0.003 | 9 | 0.84 | - | - | - | - |
| ELSC | Overall | 35 | 15 | 0.004 | 13 | 0.84 | 0.12 | **0.01** | 12.21 | 87.79 |
| *Stygiopontius hispidulus* | EPR | Bio\_9 | 32 | 12 | 0.01 ± 0.003 | 12 | 0.87 | - | - | - | - |
| EPR | Tica | 7 | 6 | 0.01 ± 0.004 | 5 | 0.91 | - | - | - | - |
| EPR | Marker-28 | 16 | 8 | 0.004 ± 0.003 | 9 | 0.91 | - | - | - | - |
| EPR | V-Vent | 27 | 9 | 0.004 ± 0.003 | 12 | 0.88 | - | - | - | - |
| GC | Rebecca's Roost | 1 | - | - | - | - | - | - | - | - |
| EPR+GC | Overall | 83 | 12 | 0.004 | 21 | 0.89 | **0** | 0.65 | 0 | 100 |
| *Stygiopontius lauensis* | ELSC | Kilo Moana | 7 | 14 | 0.01 ± 0.01 | 7 | 1 | - | - | - | - |
| ELSC | Tahi Moana | 32 | 22 | 0.02 ± 0.01 | 22 | 0.98 | - | - | - | - |
| ELSC | ABE | 55 | 47 | 0.02 ± 0.01 | 43 | 0.99 | - | - | - | - |
| ELSC | Tu'i Malila | 78 | 42 | 0.02 ± 0.01 | 31 | 0.96 | - | - | - | - |
| ELSC | Mangatolo | 77 | 55 | 0.01 ± 0.01 | 47 | 0.97 | - | - | - | - |
| ELSC | Tow Cam | 44 | 37 | 0.01 ± 0.01 | 28 | 0.97 | - | - | - | - |
| Futuna | Fatu Kapa | 77 | 46 | 0.01 ± 0.01 | 37 | 0.93 | - | - | - | - |
| ELSC + Futuna | Overall | 370 | 70 | 0.004 ± 0.003 | 149 | 0.96 | 0.02 | **0** | 2.5 | 97.5 |
| *Stygiopontius* aff. *lauensis* 1 | North Fiji | Phoenix | 62 | 47 | 0.007 ± 0.004 | 38 | 0.91 | - | - | - | - |
| *Stygiopontius* aff. *lauensis* 2 | Woodlark | La Scala | 85 | 48 | 0.005 ± 0.003 | 48 | 0.9 | - | - | - | - |
| *Stygiopontius* aff. *lauensis* 3 | Manus | Pacmanus | 35 | 26 | 0.003 ± 0.002 | 22 | 0.88 | - | - | - | - |
| *Stygiopontius pectinatus* | MAR | TAG | 18 | 11 | 0.004 ± 0.003 | 9 | 0.94 | - | - | - | - |
| MAR | Snake-pit | 15 | 10 | 0.005 ± 0.004 | 7 | 0.94 | - | - | - | - |
| MAR | Overall | 33 | 12 | 0.005 | 14 | 0.93 | 0 | 0.81 | 0 | 100 |
| *Stygiopontius senokuchiae* | IBM Arc | Bayonnaise | 3 | 0 | 0 | 1 | - | - | - | - | - |
| IBM Arc | Myojin-sho | 3 | 0 | 0 | 1 | - | - | - | - | - |
| IBM Arc | Overall | 6 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 100 |
| *Stygiopontius* sp. 1 | CIR | Kairei | 17 | 12 | 0.004 ± 0.003 | 12 | 0.96 | - | - | - | - |
| *Stygiopontius* sp. 2 | CIR | Kairei | 4 | 4 | 0.01 ± 0.01 | 4 | 1 | - | - | - | - |
| *Stygiopontius senckenbergi* | Okinawa Trough | Sakai | 3 | 1 | 0.001 ± 0.002 | 2 | 0.67 | - | - | - | - |

**Table 4: Demographic parameters calculated for each putative species belonging to the Dirivlutidae (*Stygiopontius*).**

The demographic histories of the *Cox1* gene for all *Stygiopontius* species. Parameters calculated: number of sequences (Nseq), number of haplotypes (Nhap), Tajima’s *D*, Fu’s *Fs*, Sum of Squared Deviation (SSD) and the raggedness index (*rg*).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Species | Region | Site | NSeq | Nhap | Tajima's *D* | Fu's *Fs* | SSD | *rg* |
| *Stygiopontius brevispina* | ELSC | Kilo Moana | 8 | 7 | -1.48(*p* = 0.07) | -1.18527(*p* = 0.14) | 0.06(*p* = 0.56) | 0.20(*p* = 0.55) |
| ELSC | ABE | 1 | - | - | - | - | - |
| ELSC | Tu'i Malila | 25 | 9 | -1.02(*p* = 0.18) | -1.89657(*p* = 0.16) | 0.03(*p* = **0.03**) | 0.09(*p* = **0.02**) |
| ELSC | Overall | 34 | 13 | -1.25(*p* = 0.13) | -1.54(*p* = 0.15) | 0.04(*p* = 0.30) | 0.15(*p* = 0.29) |
| *Stygiopontius hispidulus* | EPR | Bio\_9 | 32 | 11 | -0.27(*p* = 0.44) | -3.32(*p* = 0.05) | 0.02(*p* = **0.00**) | 0.06(*p=***0.04**) |
| EPR | Tica | 7 | 5 | 0.85(*p* = 0.83) | -0.8(*p* = 0.25) | 0.074(*p*=0.12) | 0.24(p=0.16) |
| EPR | Marker-28 | 16 | 9 | 0.02(*p* = 0.55) | -3.57(*p* = **0.01**) | 0.02(*p* = 0.29) | 0.07(*p* = 0.3) |
| EPR | V-Vent | 27 | 12 | 0.11(*p* = 0.58) | -4.85(*p* = **0.01**) | 0.03(*p* = **0.02**) | 0.12(*p* = **0.01)** |
| GC | Rebecca's Roost | 1 | - | - | - | - | - |
| EPR+GC | Overall | 83 | 21 | 0.18(*p* = 0.60) | -3.13(*p* = 0.07) | 0.03(*p* = 0.10) | 0.12(*p* = 0.12) |
| *Stygiopontius lauensis* | ELSC | Kilo Moana | 7 | 7 | 0.37(*p* = 0.63) | -2.55(*p* = **0.04**) | 0.08(*p* = 0.06) | 0.19(*p* = 0.19) |
| ELSC | Tahi Moana | 32 | 22 | 0.38*(*p = 0.73) | -6.45(*p* = **0.02**) | 0.008(*p* = 0.37) | 0.007(*p* = 0.82) |
| ELSC | ABE | 55 | 47 | -1.08(*p* = 0.12) | -24.76(*p* = **0**) | 0.004(*p* = 0.52) | 0.004(*p* = 0.65) |
| ELSC | Tu'i Malila | 78 | 45 | -0.99(*p* = 0.17) | -24.72(*p* = **0**) | 0.01(*p* = 0.50) | 0.009(*p* = 0.92) |
| ELSC | Mangatolo | 77 | 47 | -1.53(*p* = **0.04**) | -25.25(*p* = **0)** | 0.004(*p* = 0.47) | 0.02(*p* = 0.17) |
| ELSC | Tow Cam | 44 | 28 | -1.02(*p* = 0.16) | -13.84(*p* = **0**) | 0.006(*p* = 0.33) | 0.01(*p* = 0.1) |
| Futuna | Fatu Kapa | 77 | 37 | -1.02(*p* = 0.09) | -19.61(*p =* **0**) | 0.009(*p* = 0.39) | 0.03(*p* = 0.21) |
| ELSC + Futuna | Overall | 370 | 149 | -1.53(*p* = **0.03**) | -24.45(*p* = **0**) | 0.005(*p* = 0.42) | 0.008(*p* = 0.47) |
| *Stygiopontius* aff*. lauensis* 1 | North Fiji | Phoenix | 62 | 38 | -1.93(**0.01**) | -25.82227(**0**) | 0.01289(*p* = 0.72) | 0.02(*p* = 0.76) |
| *Stygiopontius* aff. *lauensis* 2 | Woodlark | La Scala | 85 | 48 | -2.29(**0**) | -26.79155(**0**) | 0.008(*p* = **0**) | 0.04(*p* = **0.01**) |
| *Stygiopontius* aff. *lauensis* 3 | Manus | Pacmanus | 35 | 23 | -2.27(**0.004**) | -15.6716(**0**) | 0.003(*p* = 0.22) | 0.05(*p* = **0.04**) |
| Stygiopontius pectinatus | MAR | TAG | 18 | 9 | -1.24(*p* = 0.1) | -4.34(*p* = **0.01**) | - | - |
| MAR | Snake-pit | 15 | 7 | -0.86(*p* = 0.21) | -2.55(*p* =0.04) | - | - |
| MAR | Overall | 33 | 14 | -1.04(*p* = 0.15) | -3.44(*p* = **0.02**) | 0.02(*p* = 0.5) | 0.04*(*p = 0.71) |
| *Stygiopontius senokuchiae* | IBM Arc | Bayonnaise | 3 | 1 | 0 | 0 | 0 | 0 |
| IBM Arc | Myojin-sho | 3 | 1 | 0 | 0 | 0 | 0 |
| IBM Arc | Overall | 6 | 1 | 0 | 0 | 0 | 0 |
| *Stygiopontius* sp. 1 | CIR | Kairei | 17 | 12 | -1.44(*p* = 0.07) | -9.34(*p* = **0.00**) | 0.01(*p* = 0.25) | 0.07(*p* = 0.07*)* |
| *Stygiopontius* sp. 2 | CIR | Kairei | 4 | 4 | -0.84(*p* = 0.08) | -0.29(*p* = 0.26) | 0.18(*p* = **0.03**) | 0.67(*p* = 0.24) |
| *Stygiopontius senckenbergi* | Okinawa Trough | Sakai | 3 | 2 | 0 | 0.2(*p* = 0.4) | - | - |