

**Morphometric Comparison of Two Rare Catfishes,
Clarias nieuhofii and *Clarias meladerma*, from the Sirindhorn Swamp Forest,
Narathiwat Province, Southern Thailand**

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Abstract

Background and Objectives: Princess Sirindhorn Wildlife Sanctuary (Pru To Daeng) contains the largest remaining primary peat swamp forest in Thailand and represents a distinctive freshwater ecosystem characterized by acidic, waterlogged conditions and high organic matter. This habitat supports diverse freshwater fishes that are highly specialized for survival in hypoxic blackwater environments. Among them, walking catfishes of the genus *Clarias* exhibit notable morphological and physiological adaptations, including elongated bodies, scaleless skin, dorsoventrally flattened heads, four pairs of barbels, and suprabranchial organs that enable aerial respiration. The genus *Clarias* comprises approximately 62 species distributed across Africa and Asia. In Thailand, five species are recognized. While *C. batrachus* and *C. macrocephalus* are economically important, *C. meladerma*, *C. leiacanthus*, and *C. nieuhofii* are relatively rare and strongly associated with swamp forest habitats. Although *C. nieuhofii* and *C. meladerma* are classified as Least Concern, both exhibit restricted distributions and high ecological specialization, making them particularly sensitive to habitat alteration. Morphometric analysis provides a robust quantitative approach to investigating body-shape variation in relation to taxonomy, ecology, and adaptive differentiation. However, morphometric data for *Clarias* remain limited, as previous studies have focused mainly on commercially important species, leaving habitat-specialist taxa poorly documented. This study aims to (1) quantify and compare the morphometric characteristics of *C. nieuhofii* and *C. meladerma*, (2) examine sexual dimorphism

within each species, and (3) evaluate the effectiveness of principal component analysis (PCA) in discriminating interspecific morphological variation.

Methodology: Twenty-six slender walking catfish (*Clarias nieuhofii*) and thirty-four black catfish (*Clarias meladerma*) were collected from the Sirindhorn Swamp Forest, Narathiwat Province, Thailand. External morphological traits, including coloration, body form, and fin and barbel characteristics, were documented. Twenty-four morphometric characters were measured using Vernier calipers following the Department of Fisheries (2007). These measurements included major body lengths, head dimensions, fin lengths, barbel lengths, and body depths, and were expressed as %SL and %HL. Mean and standard deviation were calculated, and differences between sexes and between species were analyzed using independent *t*-tests. To remove size effects prior to multivariate analysis, morphometric variables were adjusted using Turan's (1999) ratio-based log transformation. Principal component analysis (PCA) was then applied to evaluate morphological separation between the two species.

Main Results: Clear interspecific differences in external morphology were observed between *Clarias nieuhofii* and *C. meladerma*. *Clarias nieuhofii* exhibited an elongate, slender body with a laterally flattened profile and distinct white neuromast markings arranged in 13–20 rows along the lateral surfaces. The head was relatively small and blunt, bearing four pairs of long barbels. The dorsal, anal, and caudal fins were continuous, with a rounded caudal fin tip, and body coloration ranged from dark to reddish-brown. In contrast, *C. meladerma* displayed a shorter, more robust body form with uniform dark black coloration and no visible spots. This species possessed serrated pectoral fin spines and a comparatively taller dorsal fin, resulting in a stockier appearance typical of non-slender walking catfishes. Sexual dimorphism in *C. nieuhofii* was present but limited. Of the 24 morphometric variables analyzed, four differed significantly between sexes. Males exhibited significantly greater total length (TL), standard length (SL), and lower jaw length (LLJ), indicating larger overall body size, whereas females showed significantly larger eye diameter (ED). All remaining variables, including head dimensions, body depth, fin lengths, and caudal peduncle depth, did not differ significantly. Principal component analysis (PCA) revealed partial separation between males and females, suggesting modest sex-related morphological variation. In contrast, sexual dimorphism in *C. meladerma* was minimal. Among all variables examined, only standard length (SL) differed significantly between sexes, with males showing slightly greater values. All other measurements, including head proportions, fin dimensions, eye diameter, and barbel lengths, showed no significant differences. PCA supported these results, as male and female individuals exhibited substantial overlap in multivariate space. Interspecific comparisons revealed pronounced morphological divergence between the two species. Twenty-one of the 24 morphometric variables differed significantly, with measurements related to head size, body depth, fin lengths, pelvic and anal regions, and

barbel lengths consistently higher in *C. nieuhoftii*, reflecting its elongated morphology. Only TL, caudal peduncle depth (CPD), and mouth width (WM) showed no significant differences. PCA further confirmed interspecific differentiation, with the first two principal components explaining 59.44% of the total variance, and PC1 clearly separating the species, despite minor overlap.

Conclusions: Morphometric comparison of *Clarias nieuhoftii* and *C. meladerma* from the Sirindhorn Swamp Forest was based on 24 variables expressed as %SL and %HL. Sexual dimorphism was evident in *C. nieuhoftii*, with significant differences in TL, SL, ED, and LLJ, whereas *C. meladerma* showed minimal sexual differentiation, with significance detected only in SL. Interspecific comparisons revealed significant differences in 21 of the 24 morphometric variables. Principal component analysis (PCA) explained 59.44% of the total variance and clearly separated the two species in multivariate space. These results indicate pronounced morphological divergence likely associated with ecological specialization in peat-swamp habitats and provide baseline data for future conservation and monitoring efforts.

Keywords: morphometrics; *Clarias nieuhoftii*; *Clarias meladerma*; freshwater biodiversity; peat swamp forest

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Introduction

Princess Sirindhorn Wildlife Sanctuary (Pru To Daeng) is the largest remaining primary peat swamp forest in Thailand and represents an important example of this unique ecosystem. Covering nearly 20,260 ha across Muang, Takbai, Sungai Kolok, and Sungaipadee districts of Narathiwat Province, the sanctuary is situated approximately 1,140 km south of Thailand along the eastern coastline near the Malaysian border. The climate is tropical rainforest with consistently high temperatures and heavy rainfall throughout the year. The core sanctuary is managed by the Royal Forest Department for biodiversity conservation and research, while the surrounding privately owned lands are dominated by agriculture and human settlements. Local communities depend on the forest for fisheries, melaleuca logging for charcoal production, and other household uses. The sanctuary supports exceptional biodiversity, including at least 470 plant species, 60 mammals, 217 birds, 62 fish, 52 reptiles, 19 amphibians, and 106 butterflies, with notable fish such as the nationally vulnerable *Rasbora heteromorpha*, *R. pauciperforata*, *Indostomus paradoxus*, and *Chaca bankanensis*. Peat-swamp conditions such as hypoxia, high acidity, stagnant water, and dense vegetation drive distinct morphological adaptations in fishes like *Clarias*. Low oxygen favors enlarged head and respiratory structures, while acidic, energy-limited environments promote more

elongated, streamlined bodies. Complex habitats select for slender forms and narrower heads for easier movement, and low-visibility conditions favor longer barbels for sensory function. These pressures result in measurable morphometric traits, including increased head size, reduced body depth, and extended barbels (Forest Research Center, 2000).

Catfishes of the genus *Clarias* (Siluriformes: Clariidae) inhabit a wide range of freshwater environments and are characterized by scaleless skin, elongated bodies, dorsoventrally flattened heads, and four pairs of long barbels. A defining feature of the genus is the presence of specialized suprabranchial (“dendritic”) organs that enable aerial respiration and limited terrestrial movement, giving rise to the common name “walking catfish.” The genus comprises approximately 62 species distributed across Africa and Asia. In Thailand, five species are recognized: *Clarias batrachus*, *C. macrocephalus*, *C. meladerma*, *C. leiacanthus*, and *C. nieuhofii*. While *C. batrachus* and *C. macrocephalus* are economically important, the remaining species are relatively rare and strongly associated with specialized habitats. The slender walking catfish (*C. nieuhofii*), classified as Least Concern (LC), is restricted to Southeast Asia and typically inhabits acidic, stagnant waters in tropical swamp forests from the Kra Isthmus south to Malaysia and Borneo. The black catfish (*C. meladerma*), also listed as Least Concern, occurs from the Mekong Basin to Indonesia and the Philippines but is rare and habitat-specialized in eastern and southern Thailand. Princess Sirindhorn Wildlife Sanctuary, therefore, represents a critical refuge for these peat-swamp-associated freshwater fishes. (Sudarto & Pouyaud, 2005; Pouyaud *et al.*, 2009; Rainboth, 1996; Kottelat, 2001; Saenjundaeng, 2014; Panitvong, 2020; Chhuoy *et al.*, 2024; Froese & Pauly, 2025; IUCN, 2025).

Morphometrics, the quantitative analysis of organismal form, is widely used to assess developmental variation, ecological relationships, and evolutionary significance (Roth & Mercer, 2000; Monteiro & Nogueira, 2009; Wahl, 2012; Dwivedi & De, 2024). However, morphometric information for the genus *Clarias* remains limited, especially non-economic species and peat-swamp specialist *Clarius* with most studies focusing on commercially important species such as *C. batrachus* and *C. gariepinus*. Additional data mainly come from taxonomic descriptions of newly identified species (Lim & Ng, 1999; Ng, 1999; Teugels *et al.*, 2001; Sudarto *et al.*, 2004; Ng *et al.*, 2011; Fazazi *et al.*, 2019). Among these, *Clarias nieuhofii* and *C. meladerma* are of particular interest as they are closely associated with peat swamp habitats and exhibit adaptations to extreme environmental conditions. Despite their ecological relevance, both species remain poorly studied, especially in terms of morphological variation and differentiation. Their similar external appearance and overlapping distributions further complicate species identification, highlighting the need for quantitative approaches. This study addresses a critical gap in the taxonomy and ecology of peat-swamp catfishes by providing detailed morphometric data and applying multivariate

statistical analysis to distinguish between species and sexes. Such information is essential for improving species identification, understanding morphological variation, and supporting conservation efforts for freshwater biodiversity in threatened peat swamp ecosystems. This study investigates the morphometrics of two *Clarias* species inhabiting the Sirindhorn Swamp Forest in Narathiwat Province. It aims to identify morphological differences between species and between sexes through detailed statistical analysis of morphometric parameters, and to visualize shape variation among individuals using principal component analysis (PCA).

Methodology

Twenty-six slender walking catfish (*Clarias nieuhofii*), comprising 13 males and 13 females, and 34 black catfish (*Clarias meladerma*), comprising 19 males and 15 females, Sex can be determined by external features, such as genitalia, were collected from the Sirindhorn Swamp Forest (Pru To Daeng swamp forest) in Narathiwat Province, Thailand. Sampling was conducted by obtaining freshly caught natural specimens from local fishermen operating in the study area between August 2020 and January 2022 (Figure 1). The area consists mainly of low-lying, swampy terrain (0–14 m above sea level), with peat soils rich in organic matter (>30%) and year-round high-water levels (~90–100 cm) that are characteristically acidic (pH 4.0–5.5). Specimens were collected to record external morphological features, including colors, patterns, body shapes, as well as characteristics of the heads, mouths, barbels, and fins. All experiments were performed in strict accordance with ethical protocols approved by the Ethics Committee of Prince of Songkla University (Ref No. 4/2020).

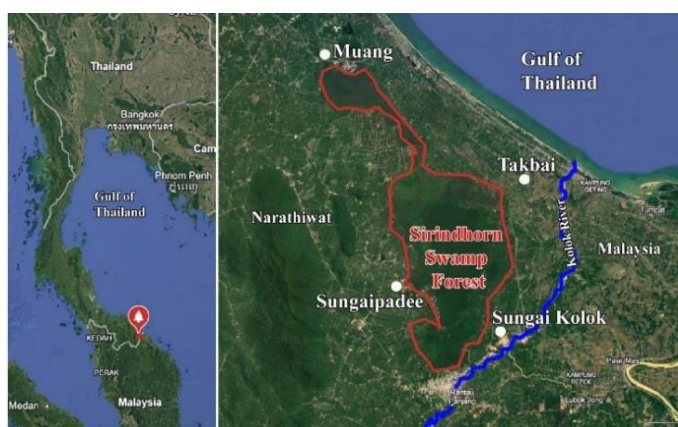


Figure 1 Map of Sirindhorn Swamp Forest, Narathiwat Province, Thailand, showing the sampling sites of the slender walking catfish (*Clarias nieuhofii*) and the black catfish (*Clarias meladerma*). Map modified from Google Earth.

Twenty-four morphometric measurements were recorded using a Vernier caliper following the methodology outlined by the Department of Fisheries (2007) (Figure 2). These measurements included: total length (TL), standard length (SL), head length (HL), head width (HW), interorbital length (IL), head depth (HD), snout length (SNOL), predorsal length (PDL), body depth at dorsal fin origin (BD), body depth at anus (BA), caudal peduncle depth (CPD), prepelvic length (PL), pelvic to vent distance (PVD), pectoral fin length (PFL), dorsal fin length (DFL), pelvic fin length (PELFL), anal fin base width (AFL), anal fin base length (AFBL), caudal fin length (CFL), eye diameter (ED), width of mouth (WM), length of lower jaw (LLJ), maxillary barbel length (MBL), and rostral barbel length (RBL).

Mean and standard deviation were calculated, and all morphometric measurements were expressed as %SL and %HL. Differences between sexes and between the two catfish species were analyzed using independent t-tests (pooled comparison), following the approaches of Teugels *et al.* (2001) and the Department of Fisheries (2007). Size adjustment of each morphometric parameter was performed using the ratio adjustment method for principal component analysis (PCA) as described by Turan (1999), using the following formula:

$$M_{adj} = \log (M)/\log (SL) = \log (M/SL) \quad (1)$$

M_{adj} = Adjusted parameter, M=Direct measurement, SL=Standard length

All statistical analyses can be conducted using SPSS (version 26), with significance assessed at $\alpha = 0.05$ unless otherwise adjusted for multiple testing.

Results

External Morphological Characteristics of *Clarias nieuhofii* and *Clarias meladerma*

The slender walking catfish (*Clarias nieuhofii*) exhibits an elongate (19.20-39.40 cm), slender body with a laterally flattened profile and distinct white lateral spots (putatively associated with neuromasts) markings along the body. The head is small (4.60-6.52 cm), short, and blunt, bearing four pairs of long barbels. The pectoral and pelvic fins are relatively small (1.74-3.26 cm and 0.41-1.55 cm, respectively), with the pelvic fins positioned close to the anal fin. The dorsal, anal, and caudal fins are continuous, and the caudal fin is small (2.47-4.87 cm) with a rounded tip. The body coloration is dark to reddish-brown, characterized by approximately 13–20 rows of white spots along the lateral surfaces, excluding the abdomen. Individuals typically range from 30 to 60 cm in total length (Figure 3A). In contrast, the black catfish (*Clarias meladerma*) has a more robust, non-slender body, rounded similarly to other

walking catfish species, but the pectoral fins exhibit serrated, saw-tooth edges. The body is short (19.50-27.00 cm), covered with dark black skin, and lacks any visible spots. The dorsal fin is relatively taller compared to other *Clarias* species. Fully grown individuals reach approximately 35 cm in total length (Figure 3B).

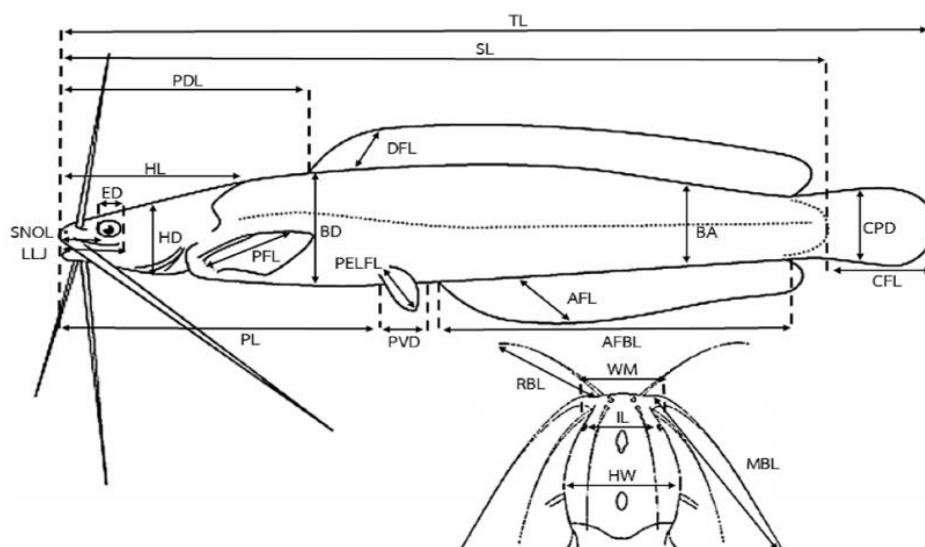


Figure 2 Morphometric measurement of catfish in 24 variables: total length (TL), standard length (SL), head length (HL), head width (HW), interorbital length (IL), head depth (HD), snout length (SNOL), predorsal length (PDL), body depth at dorsal (BD), body depth at anus (BA), caudal peduncle depth (CPD), prepelvic length (PL), pelvic to vent distance (PVD), pectoral fin length (PFL), dorsal fin length (DFL), pelvic fin length (PELFL), anal fin width (AFL), anal fin base length (AFBL), caudal fin length (CFL), eye diameter (ED), width of mouth (WM), length of lower jaw (LLJ), maxillary barbels length (MBL) and rostral barbel length (RBL)



Figure 3 External morphology of slender walking catfish; A: *Clarias nieuhofii*; B: *Clarias meladerma*

Sexual Dimorphism

*in slender walking catfish (*Clarias nieuhofii*)*

The morphometric characteristics of male and female slender walking catfish (*Clarias nieuhofii*) across 24 measured variables are presented (Table 1). Statistical comparisons using independent t-tests revealed significant sexual dimorphism in four variables: total length (TL), standard length (SL), eye diameter (ED), and lower lip–jaw distance (LLJ) ($p < 0.05$). Males exhibited greater TL (35.36 ± 5.67 cm) and SL (29.53 ± 4.90 cm) compared to females (TL: 31.60 ± 6.83 cm; SL: 27.99 ± 5.44 cm), indicating that males are generally longer bodied. In contrast, females had a significantly larger ED (0.78 ± 0.27 cm) than males (0.39 ± 0.07 cm). LLJ was also greater in males. The remaining morphometric variables, including head length (HL), head width (HW), body depth (BD), fin lengths, and caudal peduncle depth (CPD), did not differ significantly ($p > 0.05$). The morphological variation and clustering patterns between sexes were further illustrated through principal component analysis (PCA), which showed a partial separation of male and female individuals (component matrix, PC1: IL=0.953, PFL=0.948, BA=0.931, PC2: LLJ=-0.808, ED=0.707, BD=0.471) (Figure 5A).

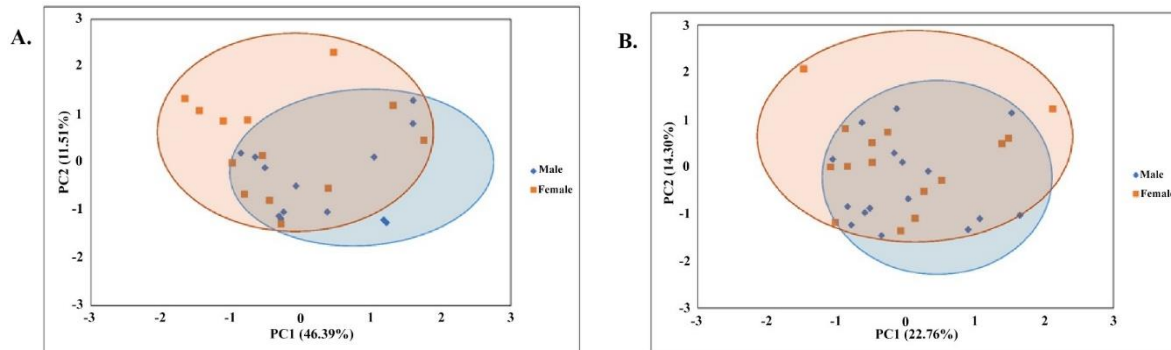


Figure 5 Principal component analysis (PCA) illustrating morphometric differentiation between males and females of (A) *Clarias nieuhofii* and (B) *Clarias meladerma*

Table 1 Morphometric measurements of male and female slender walking catfish (*Clarias nieuhofii*) and t-test comparisons across 24 variables

Morphometrics	Male (N=13)		Female (N=13)		t-test	P-value
	Range	Mean±SD	Range	Mean±SD		
TL	22.60-38.10	35.36±5.67	19.20-39.40	31.60±6.83	2.04	0.04*
SL	19.50-35.00	29.53±4.90	17.24-35.30	27.99±5.44	0.00	0.00**
HL	4.86-6.61	5.90±0.63	4.60-6.52	5.61±0.67	0.57	0.84 ^{ns}
HW	2.61-3.28	2.91±0.21	1.98-3.04	2.52±0.33	0.39	0.26 ^{ns}
IL	2.14-2.76	2.47±0.20	1.83-2.61	2.23±0.21	0.78	0.59 ^{ns}
HD	1.90-3.52	2.57±0.40	1.61-2.83	2.35±0.42	0.04	0.68 ^{ns}
SNOL	1.22-2.22	1.65±0.35	1.01-2.11	1.54±0.34	0.09	0.92 ^{ns}
PDL	5.24-8.96	7.61±1.22	4.42-10.85	7.31±1.66	0.56	0.76 ^{ns}
BD	2.14-3.87	3.06±0.59	1.95-4.06	2.74±0.62	0.05	0.48 ^{ns}
BA	2.98-4.13	3.45±0.36	2.56-3.61	3.18±0.35	0.03	0.76 ^{ns}
CPD	0.92-2.37	1.26±0.37	0.94-11.10	2.10±2.73	3.58	0.28 ^{ns}
PL	8.03-12.57	10.78±1.57	6.66-13.61	10.72±1.83	1.19	0.17 ^{ns}
PVD	0.41-1.22	0.87±0.26	0.61-1.55	0.93±0.27	0.06	0.52 ^{ns}
PFL	1.94-3.11	2.48±0.36	1.74-3.26	2.42±0.39	0.00	0.78 ^{ns}
DFL	1.16-3.65	2.67±0.65	1.85-2.81	2.26±0.28	0.99	0.28 ^{ns}
PELFL	1.13-1.83	1.53±0.24	1.32-2.02	1.59±0.18	1.58	0.31 ^{ns}
AFL	1.25-2.85	1.83±0.50	1.26-2.46	1.69±0.34	0.00	0.91 ^{ns}
AFBL	2.22-21.94	16.42±5.72	9.26-21.2	16.88±4.07	1.28	0.32 ^{ns}
CFL	2.86-4.87	3.70±0.54	2.47-4.26	3.31±0.51	0.59	0.34 ^{ns}
ED	0.33-0.59	0.39±0.07	0.50-1.25	0.78±0.27	28.93	0.00**
WM	1.16-3.15	2.26±0.56	1.41-2.77	1.99±0.38	3.76	0.60 ^{ns}
LLJ	1.10-2.43	1.69±0.39	0.80-1.95	1.34±0.35	0.48	0.04*
MBL	4.72-9.09	7.55±1.47	4.22-8.64	7.03±1.53	0.08	0.94 ^{ns}
RBL	2.91-5.64	4.06±0.86	2.22-7.25	3.97±1.31	0.72	0.81 ^{ns}

in black catfish (Clarias meladerma)

Morphometric measurements for male (N = 19) and female (N = 15) black catfish (*Clarias meladerma*) are shown in Table 2. Among the 24 variables, only SL exhibited a significant difference between sexes, with males showing slightly greater values ($p < 0.05$). All other measurements—including TL, HL, BD, HW, fin dimensions, ED, and MBL—were not significantly different ($p > 0.05$). The PCA plot (component matrix, PC1: HL=0.938, PDL=0.864,

IL=0.804, PC2: BD=-0.827, AFBL=0.646, HD=-0.640) for *C. meladerma* (Figure 5B) indicated substantial overlap between males and females, supporting the statistical findings that sexual dimorphism in this species is minimal and limited primarily to body length. The core variables contributing most strongly to PC1/PC2 (HL, PDL, IL, BD, AFBL, and HD) also show non-significant on t-test ($p > 0.05$).

Table 2 Morphometric measurements of male and female black catfish (*Clarias meladerma*) and results of t-test comparisons across 24 variables

Morphometrics	Male (N=19)		Female (N=15)		t-test	P-value
	Range	Mean±SD	Range	Mean±SD		
TL	20.30-27.00	23.14±1.89	19.50-26.10	22.91±1.64	0.24	0.61 ^{ns}
SL	17.93-22.30	20.22±1.66	13.67-21.20	19.12±1.85	0.00	0.00**
HL	4.47-5.61	5.03±0.35	4.06-5.42	4.78±0.38	0.06	0.94 ^{ns}
HW	2.00-3.83	2.60±0.37	1.94-2.83	2.40±0.22	4.30	0.89 ^{ns}
IL	2.01-2.51	2.28±0.14	1.76-2.39	2.14±0.18	2.50	0.62 ^{ns}
HD	2.01-2.76	2.35±0.21	1.87-3.11	2.37±0.32	0.00	0.45 ^{ns}
SNOL	1.25-1.83	1.53±0.16	1.19-1.80	1.44±0.17	1.16	0.63 ^{ns}
PDL	4.83-6.65	5.61±0.44	4.46-6.96	5.45±0.58	0.98	0.44 ^{ns}
BD	1.93-3.32	2.64±0.37	1.92-3.41	2.73±0.41	0.25	0.30 ^{ns}
BA	2.84-4.00	3.35±0.36	2.33-3.82	3.22±0.36	0.05	0.82 ^{ns}
CPD	0.73-1.36	1.13±0.15	0.87-1.85	1.16±0.24	2.82	0.25 ^{ns}
PL	7.07-10.08	8.54±0.81	5.01-10.52	8.36±1.33	0.15	0.43 ^{ns}
PVD	0.44-1.51	0.97±0.27	0.53-1.22	0.87±0.20	1.04	0.32 ^{ns}
PFL	2.22-3.35	2.85±0.27	1.51-3.13	2.67±0.46	0.08	0.82 ^{ns}
DFL	2.01-3.15	2.68±0.33	1.83-2.98	2.49±0.40	2.94	0.67 ^{ns}
PELFL	0.72-2.60	1.88±0.36	1.61-2.12	1.81±0.14	1.14	0.81 ^{ns}
AFL	0.72-1.98	1.60±0.28	0.83-2.23	1.56±0.40	1.91	0.97 ^{ns}
AFBL	9.01-11.95	10.35±0.93	1.13-12.6	8.98±2.52	0.21	0.70 ^{ns}
CFL	2.22-4.07	3.20±0.40	2.07-4.37	3.29±0.48	0.91	0.13 ^{ns}
ED	0.32-0.58	0.42±0.08	0.24-0.48	0.37±0.07	0.04	0.45 ^{ns}
WM	1.39-2.48	1.84±0.32	0.42-2.00	1.51±0.38	0.15	0.09 ^{ns}
LLJ	0.67-1.85	1.30±0.36	0.86-1.61	1.22±0.23	1.23	0.93 ^{ns}
MBL	5.12-10.39	7.36±1.61	3.21-8.64	6.92±1.66	0.65	0.69 ^{ns}
RBL	4.11-8.44	5.76±1.25	2.61-8.25	5.78±1.58	1.48	0.25 ^{ns}

Inter-Specific Morphometric Variation

A comparative analysis of 24 morphometric variables between *Clarias nieuhofii* (N = 26) and *C. meladerma* (N = 34) is presented in Table 3. Significant ($p < 0.05$) interspecific differences were detected in 21 variables (some variables that show no difference will not be analyses), indicating clear morphological differentiation. Measurements related to head dimensions (HL, HW, IL, HD), body proportions (PDL, BD, BA), and fin and barbel lengths (PL, PVD, PFL, DFL, PELFL, AFL, AFBL, CFL, MBL, RBL) were consistently greater in *C. nieuhofii*. In contrast, total length (TL), caudal peduncle depth (CPD), and mouth width (WM) did not differ significantly between species ($p > 0.05$). Principal component analysis (PCA) further supported interspecific differentiation (Figure 6). The first two principal components explained 59.44% of the total variance, with PC1 (component matrix, PC1: IL=0.958, HL=0.941, BA=0.932) accounting for 52.03% and PC2 (component matrix, PC2: ED=0.802, LLJ=-0.603, CPD=0.556) for 7.41%. Specimens of *C. nieuhofii* were primarily distributed along the negative axis of PC1, whereas *C. meladerma* clustered along the positive axis. Although some overlap occurred in the central ordination space, overall clustering patterns were distinct. Variation along PC2 was limited and did not substantially improve species separation. This is consistent with the t-test results, which showed that most variables were significantly different between *C. meladerma* and *C. nieuhofii* species ($p < 0.001$) (Figure 6).

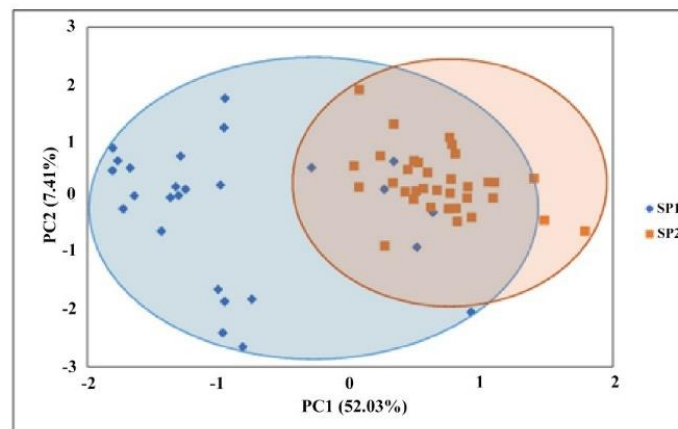


Figure 6 Principal component analysis (PCA) demonstrating the separation between slender walking catfish (*Clarias nieuhofii*, SP1) and black catfish (*Clarias meladerma*, SP2)

Table 3 Comparative morphometric measurements (%SL) of slender walking catfish (*Clarias nieuhofii*) and black catfish (*Clarias meladerma*) with t-test results across 24 variables

Morphometrics	<i>C. meladerma</i> (N=26)		<i>C. nieuhofii</i> (N=34)		t-test	P-value
	Range	Mean±SD	Range	Mean±SD		
TL	111.36-152.40	116.30±9.87	113.21-183.61	117.49±13.17	0.03	0.69 ^{ns}
SL	100.00%	100.00±0.00	100.00%	100.00±0.00	0.00	0.00 ^{**}
HL	17.13-29.23	20.40±2.79	22.65-29.70	25.01±1.47	7.96	0.00 ^{**}
HW	6.85-13.58	9.68±1.84	10.14-17.57	12.76±1.40	2.70	0.00 ^{**}
IL	6.43-12.15	8.39±1.56	10.18-12.89	11.29±0.73	13.17	0.00 ^{**}
HD	5.55-13.09	8.75±1.81	10.04-14.81	12.02±1.25	3.43	0.00 ^{**}
SNOL	3.45-7.40	5.65±1.27	6.50-9.11	7.56±0.71	11.15	0.00 ^{**}
PDL	23.20-34.82	25.99±2.27	25.39-34.52	28.16±2.07	0.22	0.00 ^{**}
BD	7.23-14.12	10.22±2.02	10.16-17.23	13.62±1.89	0.28	0.00 ^{**}
BA	8.63-16.65	11.86±2.30	13.27-19.20	16.71±1.53	3.78	0.00 ^{**}
CPD	3.03-56.35	6.53±10.23	3.90-8.81	5.79±0.91	4.50	0.67 ^{ns}
PL	30.81-42.01	37.68±3.26	36.65-52.18	42.88±4.08	0.73	0.00 ^{**}
PVD	1.18-5.54	3.28±1.20	2.35-7.94	4.70±1.23	0.00	0.00 ^{**}
PFL	4.93-15.38	8.97±2.93	9.21-16.57	14.04±1.50	10.66	0.00 ^{**}
DFL	3.74-12.72	8.77±2.06	9.95-15.49	13.14±1.35	7.89	0.00 ^{**}
PELFL	3.65-8.99	5.63±1.53	4.02-12.68	9.40±1.50	0.31	0.00 ^{**}
AFL	4.06-9.79	6.25±1.60	4.02-11.06	8.03±1.68	0.14	0.00 ^{**}
AFBL	7.16-69.58	57.53±11.47	5.59-62.50	49.40±8.45	1.93	0.00 ^{**}
CFL	8.91-16.23	12.37±1.84	11.48-24.28	16.48±2.34	0.15	0.00 ^{**}
ED	1.05-4.01	2.09±1.01	1.23-3.00	2.03±0.37	31.12	0.00 ^{**}
WM	4.63-10.16	7.44±1.38	1.98-11.59	8.57±1.63	0.49	0.07 ^{ns}
LLJ	3.26-7.60	5.32±1.25	3.02-8.64	6.37±1.29	0.10	0.03 ^{**}
MBL	12.91-40.51	26.02±6.43	23.48-50.29	36.26±7.51	3.33	0.00 ^{**}
RBL	8.38-31.12	14.78±6.18	18.55-45.83	29.17±6.37	0.31	0.00 ^{**}

Discussion

Morphometric analysis provides a robust quantitative framework for resolving taxonomic relationships among closely related fish species with high morphological similarity, while capturing intraspecific variation driven by geographic and habitat-related factors. (Fagbuaro *et al.*, 2015; Iswanto *et al.*, 2015). In the present study, sexual dimorphism in the two examined catfish species was limited. In *Clarias nieuhofii*, significant differences between

males and females were detected in only four morphometric variables: total length (TL), standard length (SL), eye diameter (ED), and lower jaw length (LLJ). This pattern is consistent with previous findings in other clariid catfishes, such as *Clarias gariepinus* in Nigeria, where males generally exhibited higher morphometric values than females, except for heart girth (Fazazi et al., 2019). In contrast, *Clarias meladerma* exhibited minimal sexual dimorphism, with a significant difference detected only in standard length (SL). Similar results have been reported for *Silurus triostegus* from the Tigris and Shatt al-Arab rivers, Iraq (Jawad & Al-Janabi, 2016). Similarly, in *Plotosus canius* from coastal waters off Port Dickson, Malaysia, the relationship between total length (TL) and standard length (SL) showed the highest regression coefficient, whereas relationships between TL and other body measurements were weak in both sexes (Usman et al., 2016). PCA results further indicated substantial overlap between males and females (Figure 5), suggesting minimal sexual contribution to overall morphometric differentiation.

In contrast, interspecific comparisons revealed substantial morphological differentiation. Twenty-one of the twenty-four morphometric variables significantly distinguished *Clarias nieuhofii* from *C. meladerma*, and the PCA results clearly separated the two species. These findings are consistent with previous studies of African and Asian *Clarias* species, which similarly reported strong interspecific divergence driven by ecological specialization and habitat-specific adaptation (Behmene et al., 2022; Pouyaud et al., 2009). Notably, females of both species exhibited greater morphometric dispersion than males as suggested by PCA dispersion (Figure 5A and B), a pattern also documented by Behmene et al. (2022), suggesting that reproductive allometry or broader ecological plasticity may contribute to the higher variability observed in females.

The effectiveness of PCA in revealing patterns of morphometric differentiation is supported by Turan et al. (2005), who demonstrated population-level differentiation of *Clarias gariepinus* across six river systems in Turkey. The observed morphological variation was associated with environmental factors such as water turbidity, temperature, depth, and flow velocity. Similarly, Mohamad (2019) showed that PCA effectively discriminated *Hemibagrus nemurus* and *H. planiceps* from the Semadang and Samunsam rivers in Malaysia, identifying pre-anal length (PAL) and pre-dorsal length (PDL) as statistically significant contributors to species separation ($P < 0.05$). Collectively, these studies highlight PCA as a powerful analytical tool for interpreting morphometric variation across multiple biological scales, including sexual dimorphism, population structure, and interspecific differentiation. Nevertheless, the need for relatively large sample sizes and multi-step analytical procedures may partly explain why PCA remains underutilized in morphometric studies of certain freshwater fish groups (Więcaszek et al., 2010; Oguntade et al., 2015; Abanikannda et al., 2019; Torgersen et al., 2023). Overall, the results presented in Figure 6 support the effectiveness of combining morphometric data with multivariate analyses, such as PCA, in

discriminating between *Clarias nieuhofii* and *C. meladerma*. However, the partial overlap observed between species suggests that integrating additional data, including meristic, genetic, or ecological information, would further enhance species discrimination and understanding of adaptive mechanisms in this group.

The morphometric differences between the two species closely reflect their ecological and functional specializations. *C. nieuhofii* exhibits a more elongate body form ($SL/BD = 9.78$) than *C. meladerma* ($SL/BD = 7.34$), may facilitate anguilliform or slithering locomotion within dense peat-swamp root systems, a trait common among benthic predators in structurally complex habitats (Nguyen, 2015). Longer barbels in *C. nieuhofii* further indicate enhanced tactile and chemosensory capabilities in dark, tannin-rich waters. Distinct coloration patterns reinforce habitat-driven divergence: the white lateral spotting of *C. nieuhofii* likely associated with disruptive camouflage among submerged woody debris, whereas the uniformly dark pigmentation of *C. meladerma* suggests a potential adaptation to concealment in fine mud substrates (Bologan, 2009; Panitvong, 2020). Collectively, these traits highlight the role of habitat structure and sensory adaptation in shaping morphological divergence among *Clarias* species and emphasize the ecological importance of peat-swamp forests for freshwater biodiversity conservation.

Conclusions

Morphometric analysis revealed clear differentiation between *Clarias nieuhofii* and *C. meladerma* in the Princess Sirindhorn peat swamp forest, with most variables showing significant interspecific differences and PCA effectively separating the two species. Sexual dimorphism was evident in *C. nieuhofii* but minimal in *C. meladerma*, indicating species-specific patterns of morphological variation. Although some key traits did not differ significantly in univariate tests, multivariate analysis captured overall shape variation, highlighting the importance of combining statistical approaches. These findings improve taxonomic resolution of peat-swamp *Clarias* and provide baseline data for future ecological and conservation studies in this threatened ecosystem.

These findings demonstrate pronounced morphological divergence between *C. nieuhofii* and *C. meladerma*, likely reflecting distinct ecological adaptations to peat-swamp environments. The results provide baseline morphometric data valuable for future ecological monitoring and conservation of freshwater fishes in Thailand's remaining peat-swamp forests. In the future, there may be integration of this data with genetics, meristic analysis (integrative approaches) or broader geographic sampling.

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