

Supplementary Information

PlanktonFlow : hands-on deep-learning classification of plankton images for biologists

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S1 Supplementary Methods

S1.1 Loss function algorithms

Algorithm 1 Computation of Focal Loss (per sample)

Require: Logits $\mathbf{o} \in \mathbb{R}^C$, ground-truth label $y \in \{1, \dots, C\}$, focusing parameter γ , optional weight vector α

Ensure: Focal loss $\mathcal{L}_{\text{focal}}$

```
1: function FOCALLOSS( $\mathbf{o}, y, \gamma, \alpha$ )
2:   Compute softmax probabilities:  $\hat{\mathbf{y}} \leftarrow \text{softmax}(\mathbf{o})$ 
3:   Extract true class probability:  $p_t \leftarrow \hat{y}_y$ 
4:   Clamp  $p_t$  to avoid  $\log(0)$  (e.g.,  $p_t \leftarrow \text{clamp}(p_t, \varepsilon, 1 - \varepsilon)$ )
5:   Compute modulating factor:  $m \leftarrow (1 - p_t)^\gamma$ 
6:   if  $\alpha$  is defined then  $a_t \leftarrow \alpha_y$  else  $a_t \leftarrow 1$ 
7:   Compute focal loss:  $\mathcal{L} \leftarrow -a_t \cdot m \cdot \log(p_t)$ 
8:   return  $\mathcal{L}$ 
9: end function
```

Algorithm 2 Computation of Label Smoothing Loss (redistributing smoothing over incorrect classes)

Require: Logits \mathbf{o} , ground-truth labels \mathbf{y} , smoothing factor ϵ , number of classes C

Ensure: Label smoothing loss \mathcal{L}_{LS}

```
1: function LABELSMOOTHINGLOSS( $\mathbf{o}, \mathbf{y}, \epsilon$ )
2:   Construct one-hot labels:  $\mathbf{y}_{\text{one-hot}}$ 
3:   Apply label smoothing:
```

$$\tilde{y}_c = \begin{cases} 1 - \epsilon & \text{if } c = y \\ \frac{\epsilon}{C-1} & \text{otherwise} \end{cases}$$

```
4:   Compute log-probabilities:  $\log \hat{\mathbf{y}} \leftarrow \log \text{softmax}(\mathbf{o})$ 
5:   Compute loss:  $\mathcal{L} \leftarrow -\sum_{c=1}^C \tilde{y}_c \cdot \log \hat{y}_c$ 
6:   return  $\mathcal{L}$ 
7: end function
```

S1.2 Learning Rate Scheduling

In addition to optimizer selection, the learning rate was dynamically adjusted throughout training using a cosine annealing schedule. Specifically, we used PyTorch’s `CosineAnnealingLR`, which gradually decreases the learning rate following a cosine function over a fixed number of epochs. This approach encourages larger updates at the beginning of training and finer adjustments toward the end, helping the model settle into better minima.

At each epoch t , the learning rate η_t is computed as:

$$\eta_t = \eta_{\min} + \frac{1}{2}(\eta_0 - \eta_{\min}) \left(1 + \cos \left(\frac{t\pi}{T_{\max}} \right) \right) \quad (\text{S1})$$

where η_0 is the initial learning rate, η_{\min} is the minimum learning rate (often set to 0), t is the current epoch, and T_{\max} is the total number of epochs before a full cosine cycle completes.

S1.3 Early Stopping Strategy

To prevent unnecessary training time, an **early stopping** mechanism was implemented (see Algorithm 3). This method monitors the validation loss and, optionally, the validation accuracy, halting training when no improvement is observed for a specified number of consecutive epochs (referred to as the *patience* parameter).

Our implementation allows for two simultaneous criteria:

- Validation loss must improve by at least a threshold δ (default: 0).
- If enabled, validation accuracy must also improve by at least δ .

Formally, let \mathcal{L}_t and \mathcal{A}_t denote the validation loss and accuracy at epoch t . Training stops if:

$$\forall k \in \{1, \dots, \text{patience}\}, \quad \mathcal{L}_{t-k} \geq \mathcal{L}_{t-k-1} - \delta \quad \text{and} \quad \mathcal{A}_{t-k} \leq \mathcal{A}_{t-k-1} + \delta$$

This dual-metric early stopping criterion improves robustness over single-metric strategies, particularly in settings where accuracy and loss are not perfectly aligned.

Algorithm 3 Early Stopping Procedure



Require: Validation loss \mathcal{L}_t , validation accuracy \mathcal{A}_t , patience p , improvement threshold δ , model M

```
1: Initialize: best_loss  $\leftarrow \infty$ , best_acc  $\leftarrow 0$ , counter  $\leftarrow 0$ 
2: for each epoch  $t$  do
3:   Evaluate current  $\mathcal{L}_t, \mathcal{A}_t$ 
4:   improved  $\leftarrow \mathbf{False}$ 
5:   if  $\mathcal{L}_t < \text{best\_loss} - \delta$  then
6:     best_loss  $\leftarrow \mathcal{L}_t$ 
7:     improved  $\leftarrow \mathbf{True}$ 
8:   end if
9:   if monitor accuracy and  $\mathcal{A}_t > \text{best\_acc} + \delta$  then
10:    best_acc  $\leftarrow \mathcal{A}_t$ 
11:    improved  $\leftarrow \mathbf{True}$ 
12:  end if
13:  if improved then
14:    counter  $\leftarrow 0$ 
15:    Save model checkpoint  $M$ 
16:  else
17:    counter  $\leftarrow \text{counter} + 1$ 
18:    if counter  $\geq p$  then
19:      Stop training
20:    end if
21:  end if
22: end for
```

S2 Additional Figures

PREDICTION: Choice of features and settings

Start prediction task

Add deep features  

You have chosen 116644 reference objects to build the Learning Set. In this last step, you can choose which features to associate with each of these objects, and start a prediction task using the Learning Set.

- Prediction will be better if you exclude features which are not related to the classification, e.g. coordinates in the raw image.
- Features with a single, constant value, or too many missing values, are useless for prediction and are automatically excluded. Some of them are listed here as a reminder.
- Missing values will be replaced by the median value for this feature from the reference objects.
- Prediction settings are recorded in EcoTaxa for the next prediction.


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Figure S1: EcoTaxa selected parameters

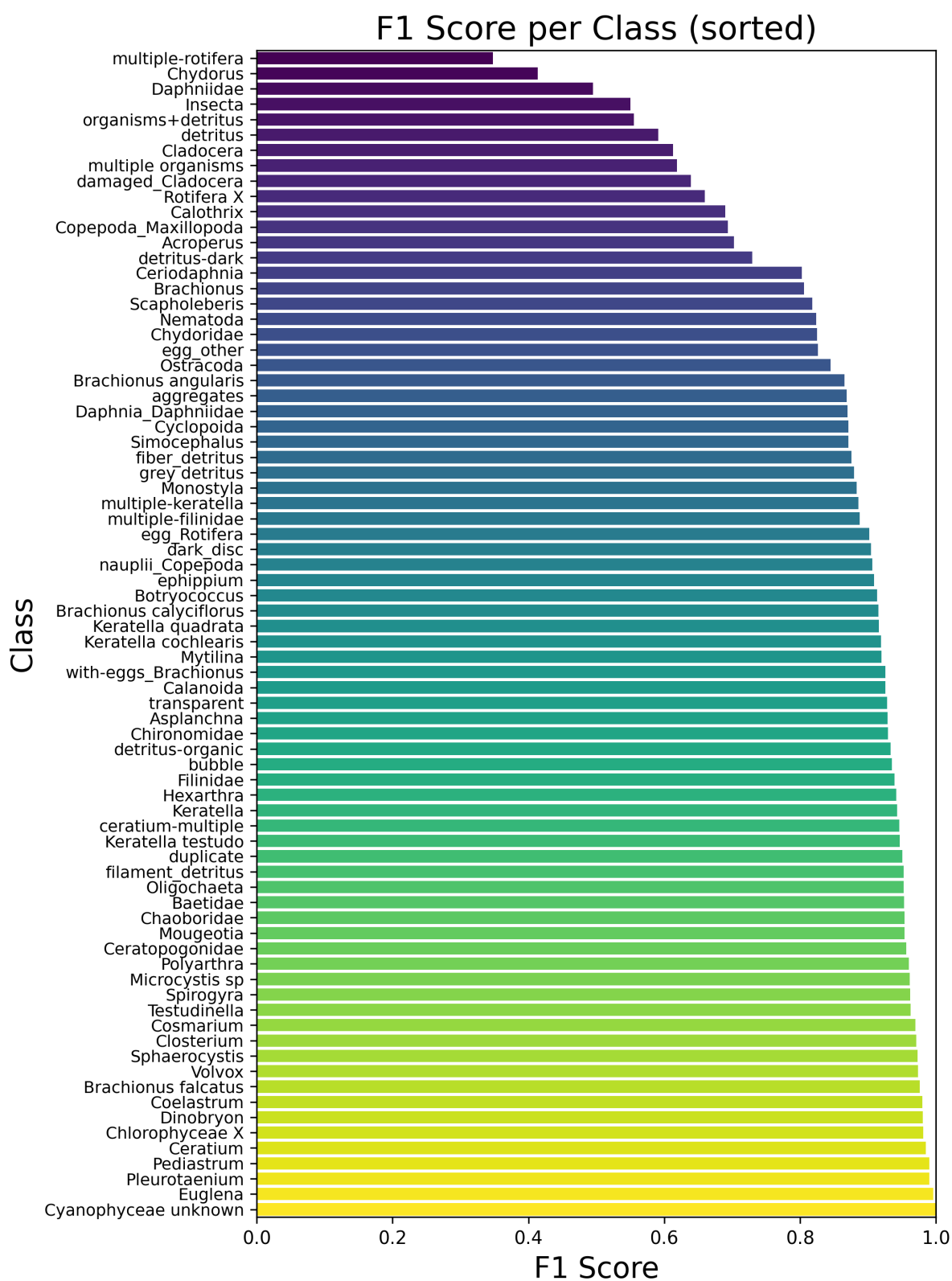


Figure S2: F1 Score per class for the best trained model (EfficientNet-B5)