

**ANALISIS FENOLOGI PERMUKAAN PADANG LAMUN BERBASIS
DINAMIKA PERSENTASE TUTUPAN MENGGUNAKAN CITRA
SENTINEL-2 DAN *RANDOM FOREST* DI PESISIR PULAU OSI, MALUKU
TAHUN 2022 - 2025
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INTISARI

Lamun merupakan tumbuhan yang hidup di lingkungan laut dangkal dan memiliki peran ekologis yang signifikan, termasuk kemampuannya dalam merespons dinamika lingkungan. Pemantauan kondisi padang lamun secara komprehensif dan berkelanjutan menjadi krusial mengingat ekosistem ini rentan terhadap tekanan antropogenik maupun perubahan iklim. Dinamika fenologi permukaan lamun yang mencerminkan pola musiman pertumbuhan dan peluruhan kanopi belum banyak dikuantifikasi di kawasan Indonesia timur, khususnya di Pesisir Pulau Osi, Maluku. Penelitian ini bertujuan untuk (1) memetakan habitat bentik di pesisir Pulau Osi menggunakan algoritma klasifikasi Random Forest (RF) dan citra Sentinel-2, (2) memodelkan persentase tutupan lamun menggunakan algoritma regresi RF, (3) menghasilkan data deret waktu tutupan lamun tahun 2022–2025 melalui penerapan model regresi secara multitemporal, dan (4) menganalisis fenologi permukaan padang lamun untuk mengidentifikasi metrik *Start of Season* (SOS), *Peak of Season* (POS), dan *End of Season* (EOS). Metodologi penelitian diawali dengan preparasi citra dan reduksi ekologis data sampel lapangan, dilanjutkan dengan ekstraksi model klasifikasi untuk masking area lamun dan regresi Random Forest untuk estimasi persentase tutupan pada citra referensi yang berdekatan dengan waktu pengambilan data lapangan. Kedua model kemudian diinferensi pada citra bimonthly untuk membangun deret waktu persentase tutupan yang selanjutnya dianalisis menggunakan metode Seasonal-Trend Decomposition using LOESS (STL). Hasil penelitian menunjukkan bahwa algoritma klasifikasi Random Forest mampu memetakan habitat bentik dengan akurasi keseluruhan sebesar 81,10%, yang tergolong sangat baik untuk klasifikasi multi-kelas di perairan dangkal optis kompleks. Pemodelan regresi persentase tutupan lamun menghasilkan koefisien determinasi (R^2)

sebesar 0,62 dan RMSE 17,95%, menunjukkan bahwa model mampu menjelaskan 62% variabilitas tutupan dengan rata-rata kesalahan estimasi kurang dari 20%, sebuah capaian yang konsisten dengan rentang performa yang dilaporkan dalam literatur pemetaan biofisik lamun berbasis Sentinel-2 di kawasan tropis. Penerapan model pada citra multitemporal menghasilkan 24 peta deret waktu *bimonthly*, dengan rata-rata tutupan komunitas berfluktuasi dalam rentang 47,97-69,43%; amplitudo sebesar 21,46% ini mencerminkan dinamika musiman moderat hingga tinggi pada padang lamun tropis. Analisis fenologi melalui dekomposisi STL berhasil mengungkap ritme biologis unimodal yang persisten antar-tahun (korelasi Pearson $r = 0,97$ antar siklus tahunan). Metrik fenologi permukaan teridentifikasi pada periode Mei-Juni untuk SOS (tutupan 55,29%), Januari-Februari untuk POS (puncak tutupan 65,84%), dan Maret-April untuk EOS (tutupan 59,06%). Analisis lebih lanjut menegaskan bahwa siklus fenologi ini tidak merespons perubahan kondisi cuaca secara instan, melainkan dikendalikan oleh mekanisme respons tertunda (*time-lag effect*), di mana dinamika tutupan lamun termanifestasi secara optimal satu hingga dua bulan setelah fluktuasi Suhu Permukaan Laut (SPL) sebagai parameter dengan tingkat korelasi marginal tertinggi.

Kata kunci : Sentinel-2, Fenologi Permukaan, Persentase Tutupan Laut, *Random Forest*, Dekomposisi STL, Pulau Osi

***SURFACE PHENOLOGY ANALYSIS OF SEAGRASS MEADOWS BASED ON
PERCENTAGE COVER DYNAMICS USING SENTINEL-2 AND RANDOM
FOREST AT OSI ISLAND COAST, MALUKU, 2022–2025***

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ABSTRACT

Seagrasses are aquatic plants inhabiting shallow marine environments that perform critical ecological functions, including the capacity to respond dynamically to environmental variability. Comprehensive and continuous monitoring of seagrass meadow conditions is imperative given the vulnerability of this ecosystem to both anthropogenic pressures and climate-driven change. The surface phenological dynamics of seagrasses — reflecting seasonal patterns of canopy growth and senescence — remain poorly quantified across eastern Indonesia, particularly along the coastal zone of Osi Island, Maluku. The present study aims to (1) map benthic habitats along the coast of Osi Island using a Random Forest (RF) classification algorithm applied to Sentinel-2 imagery, (2) model seagrass percent cover using an RF regression algorithm, (3) generate a bimonthly time-series dataset of seagrass cover spanning 2022–2025 through multitemporal application of the regression model, and (4) analyse the surface phenology of the seagrass meadow to identify the metrics of Start of Season (SOS), Peak of Season (POS), and End of Season (EOS). The methodological framework commenced with image pre-processing and ecological subsampling of field data, followed by the extraction of a classification model for seagrass area masking and an RF regression model for percent cover estimation applied to reference imagery temporally coincident with field data collection. Both models were subsequently inferred across bimonthly imagery to construct a percent cover time series, which was analysed using Seasonal-Trend Decomposition using LOESS (STL). The results demonstrate that the Random Forest classification algorithm mapped benthic habitats with an overall accuracy of 81.10%, a performance classified as excellent for multi-class classification in optically complex shallow-water

environments. Regression modelling of seagrass percent cover yielded a coefficient of determination (R^2) of 0.62 and an RMSE of 17.95%, indicating that the model explains 62% of cover variability with a mean estimation error of less than 20% an outcome consistent with the performance range reported in the literature on Sentinel-2-based biophysical mapping of seagrasses in tropical regions. Application of the model to multitemporal imagery produced 24 bimonthly time-series maps, with mean community cover fluctuating between 47.97% and 69.43%; this amplitude of 21.46% reflects moderate-to-high seasonal dynamics characteristic of tropical seagrass meadows. Phenological analysis via STL decomposition successfully revealed a persistent unimodal biological rhythm across inter-annual cycles (Pearson correlation $r = 0.97$ between annual cycles). Surface phenological metrics were identified as follows: SOS during May-June (cover: 55.29%), POS during January-February (peak cover: 65.84%), and EOS during March-April (cover: 59.06%). Further analysis confirmed that this phenological cycle does not respond instantaneously to meteorological variability; rather, it is governed by a time-lag response mechanism, whereby seagrass cover dynamics manifest optimally one to two months following fluctuations in Sea Surface Temperature (SST) the parameter exhibiting the highest marginal correlation.

Keywords : *Sentinel-2, Surface Phenology, Seagrass Percent Cover, Random Forest, STL Decomposition, Osi Island*