Supplementary file

Tip-Concentrated Electric Fields Steer Hydroxide Migration to Suppress Cathodic Scaling in Urchin-Like Ni_xMo_y–MoO_2 for Seawater Electrolysis

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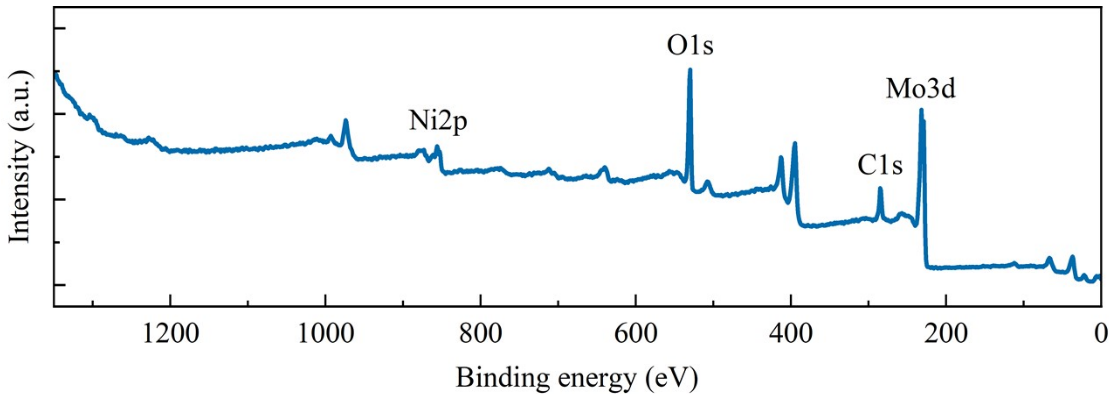

Figure S1. X-ray Photoelectron Spectroscopy (XPS) analysis of Ni_xMo_y-MoO_2@NF.

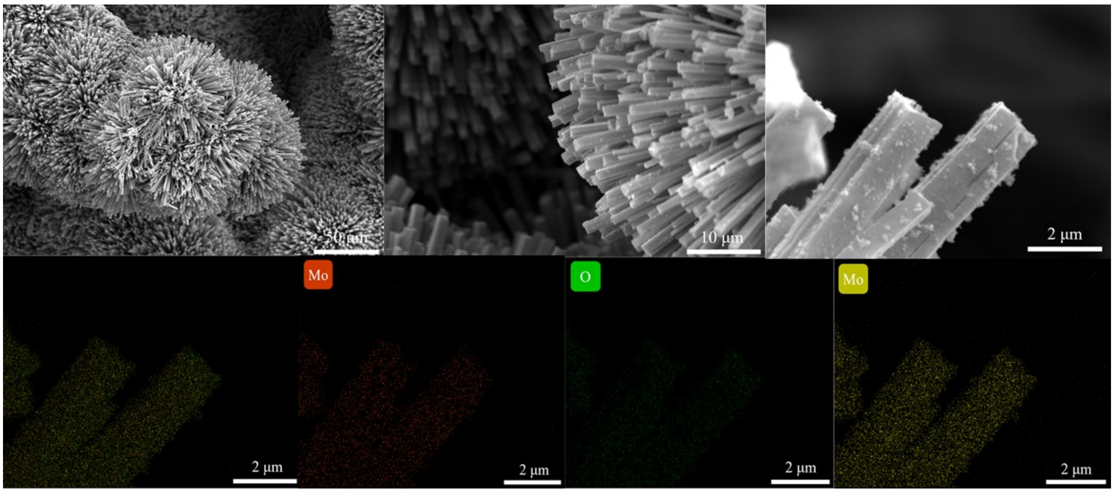

Figure S2. Scanning electron microscopy and energy dispersive spectroscopy (SEM-EDS) elemental mapping of $NiMoO_x$@NF.

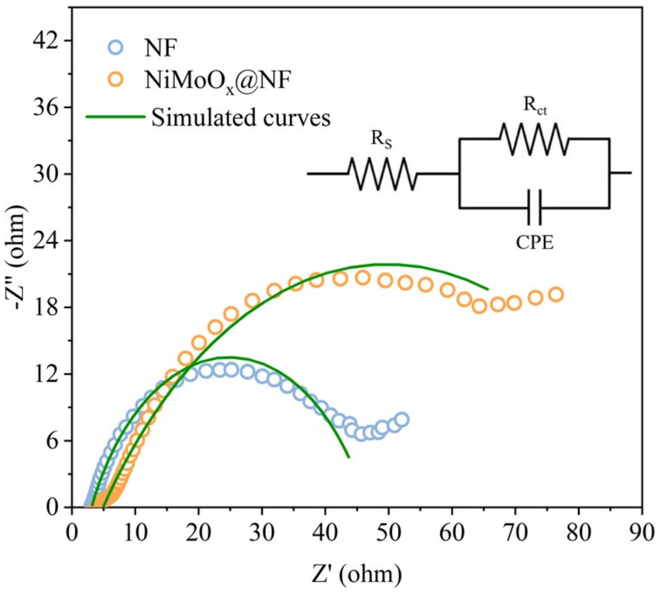

Figure S3. Electrochemical impedance spectroscopy (EIS) plots of nickel foam (NF) and $NiMoO_x$@NF.

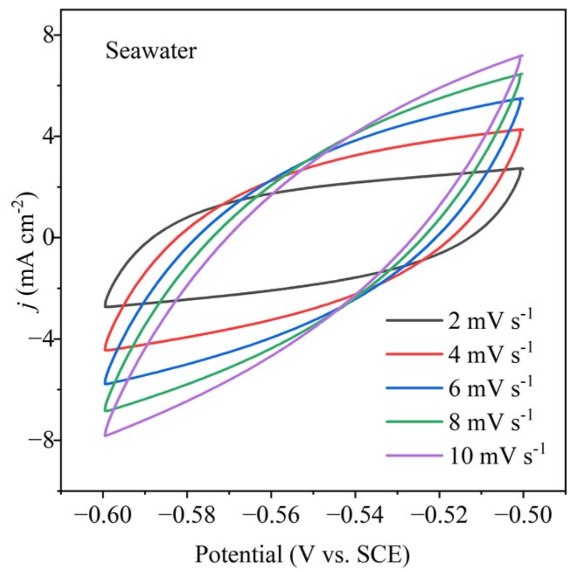

Figure S4. Cyclic voltammetry (CV) curves at various scan rates within the non-Faradaic potential region for Ni_xMo_y-MoO_2@NF in natural seawater.

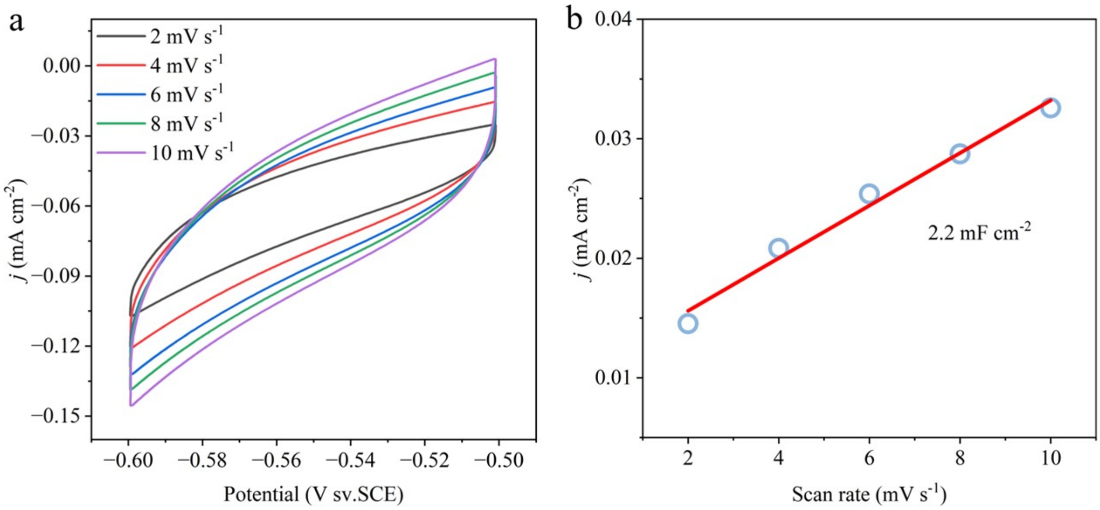

Figure S5. CV curves at various scan rates within the non-Faradaic potential region and the double-layer capacitance (C_{dl}) curves of $NiMoO_x$@NF in natural seawater.

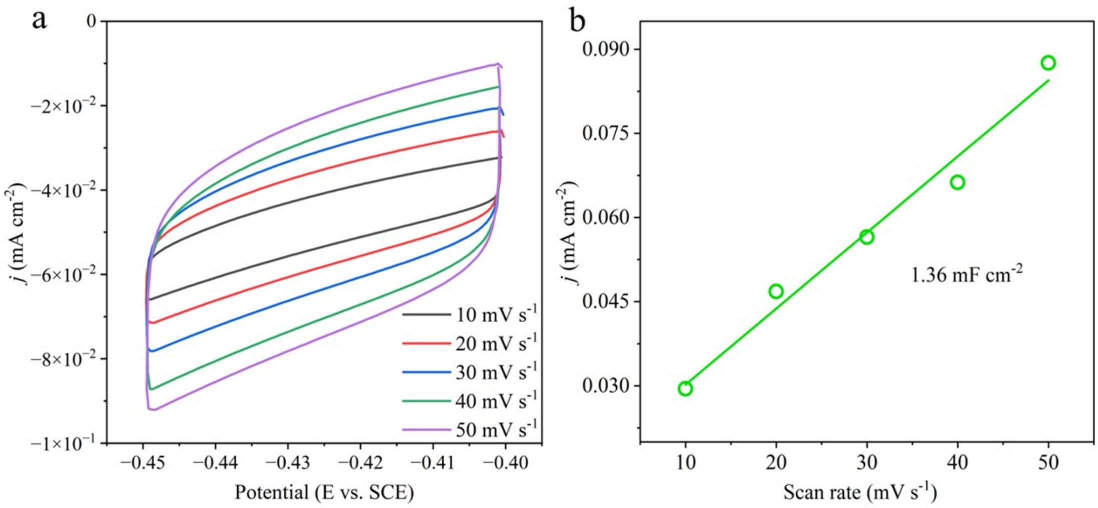

Figure S6. CV curves at various scan rates within the non-Faradaic potential region and the C_{dl} curves of NF in natural seawater.

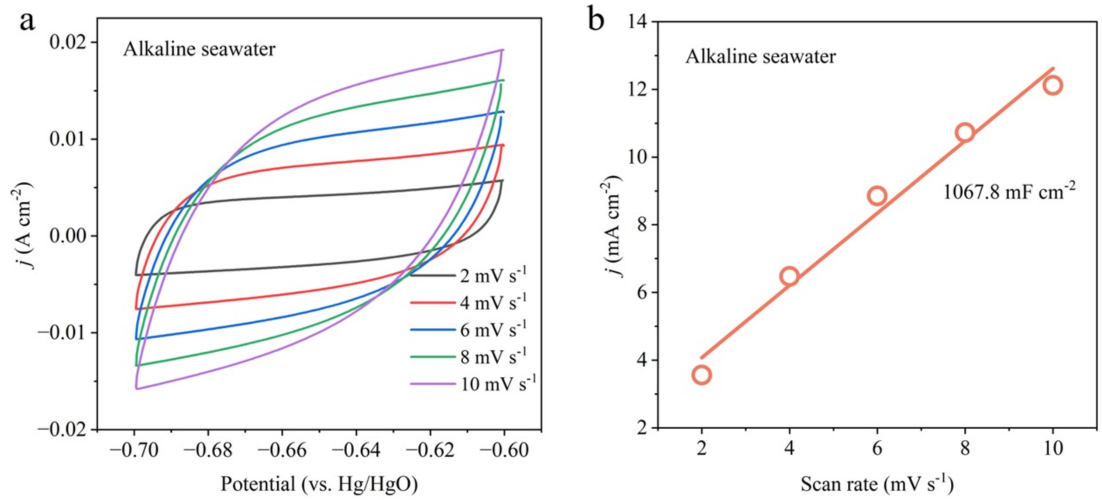

Figure S7. CV curves at various scan rates within the non-Faradaic potential region and the C_{dl} curves of Ni_xMo_y-MoO_2@NF in alkaline seawater.

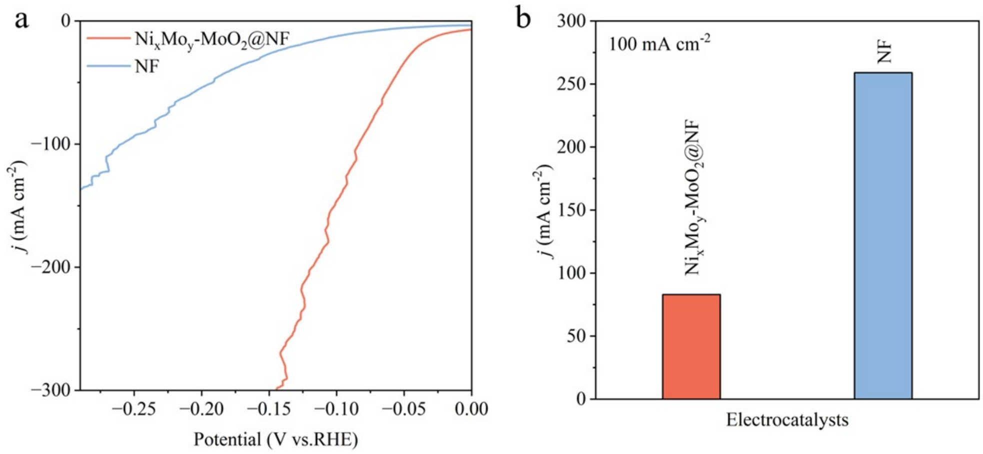

Figure S8. Linear sweep voltammetry (LSV) curves of NF and Ni_xMo_y-MoO_2@NF electrodes in alkaline seawater.

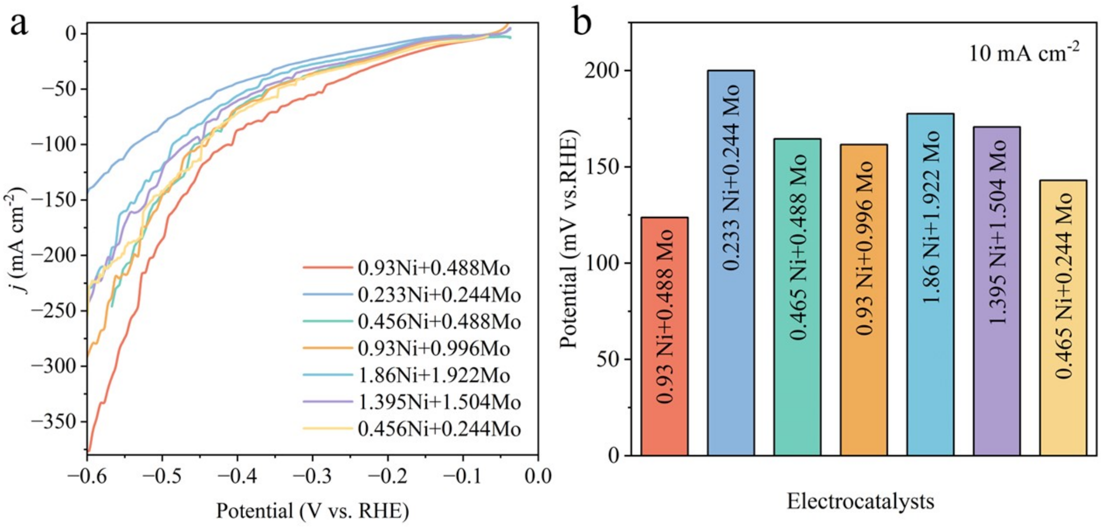

Figure S9. LSV curves of Ni_xMo_y-MoO_2@NF electrodes hydrothermally prepared in solutions with different concentrations of nickel and molybdenum salts.

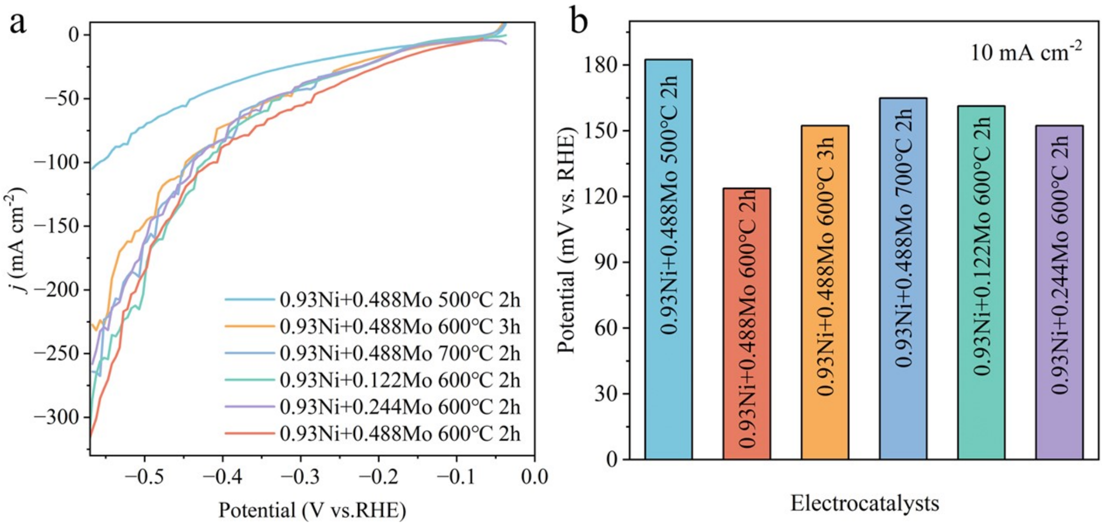

Figure S10. LSV curves of Ni_xMo_y-MoO_2@NF electrodes prepared at different annealing temperatures and durations.

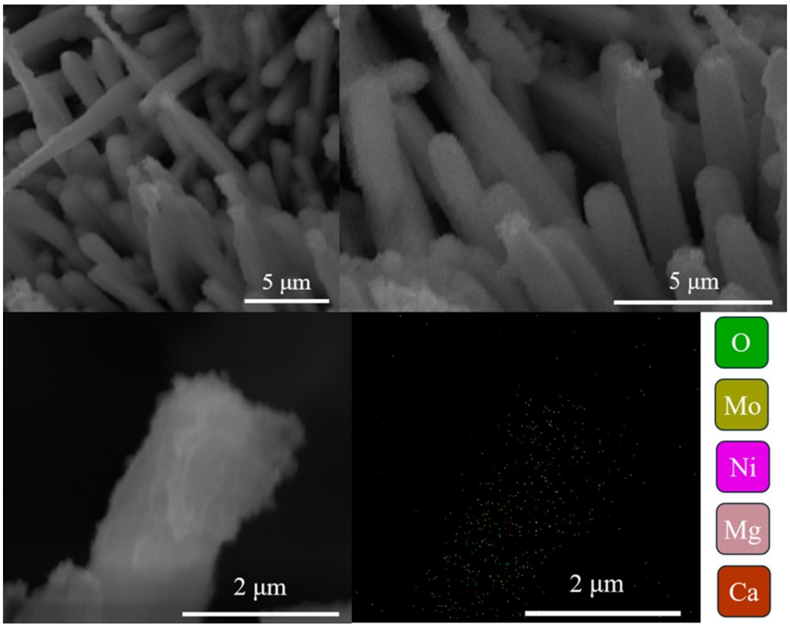

Figure S11. SEM images and EDS elemental mapping of Ni_xMo_y-MoO_2@NF after the stability test.

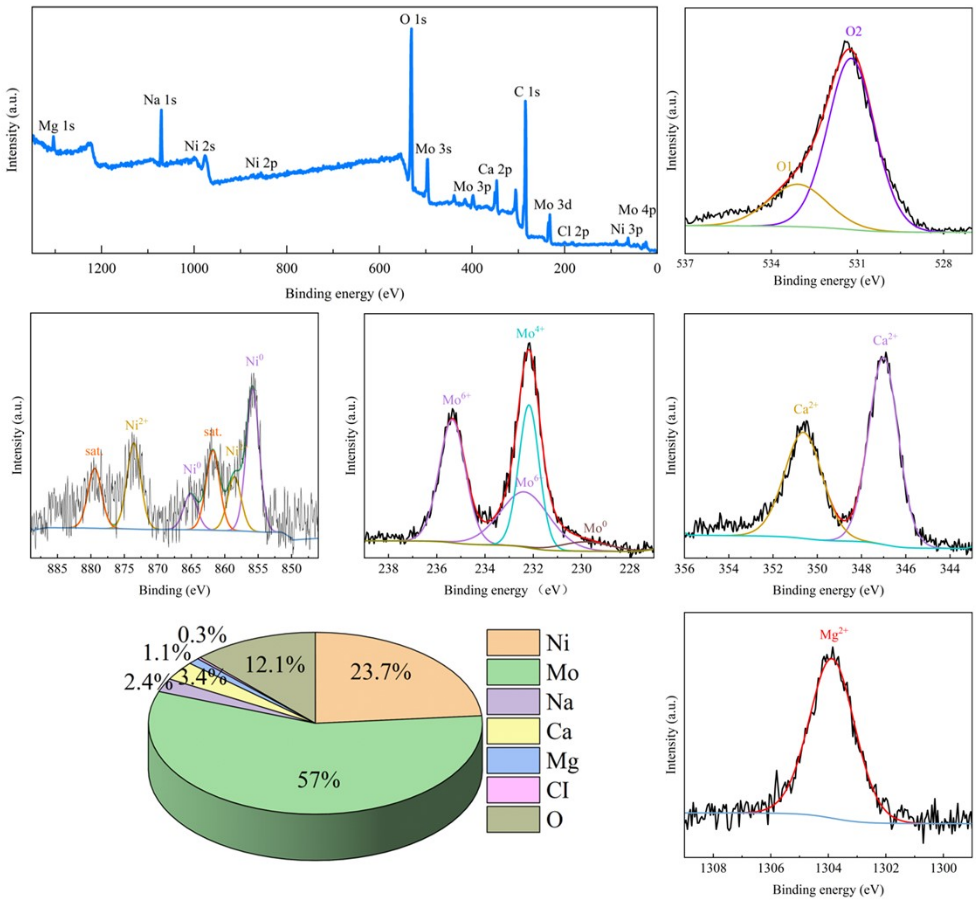

Figure S12. XPS spectra of Ni_xMo_y-MoO_2@NF after the stability test.

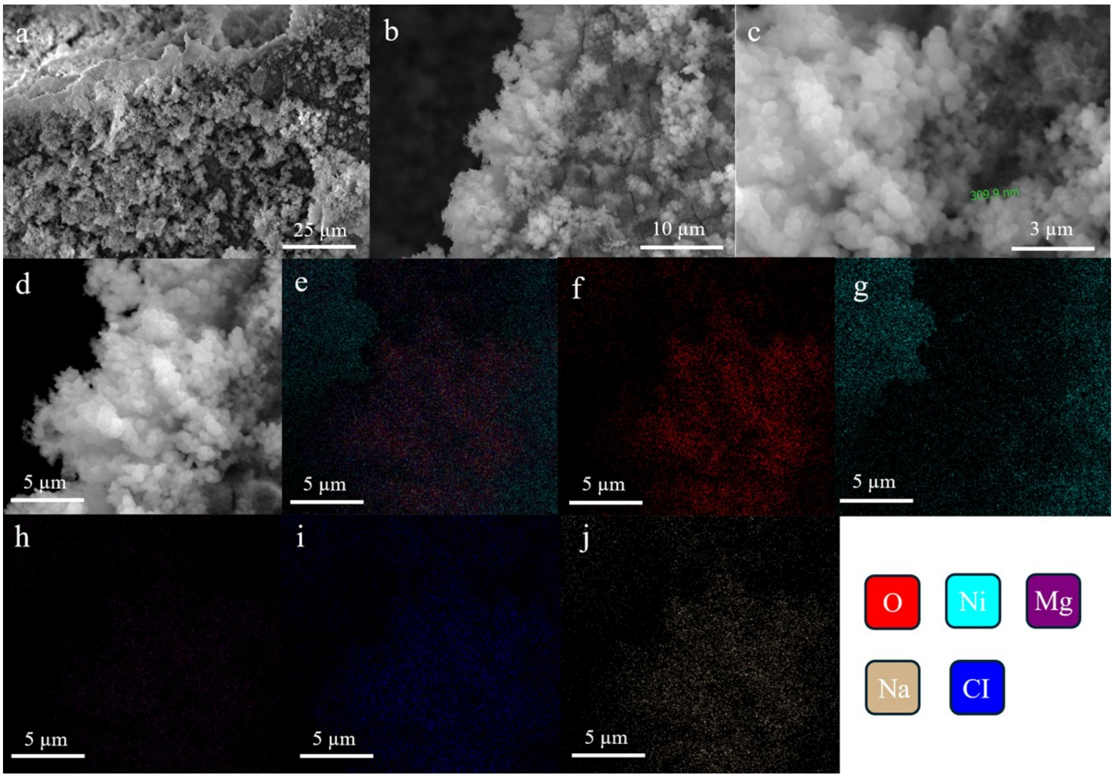

Figure S13. SEM images and EDS analysis of NF after the stability test. Corresponding EDS elemental mappings of (f) O, (g) Ni, (h) Mg, (i) Cl, and (j) Na for NF.

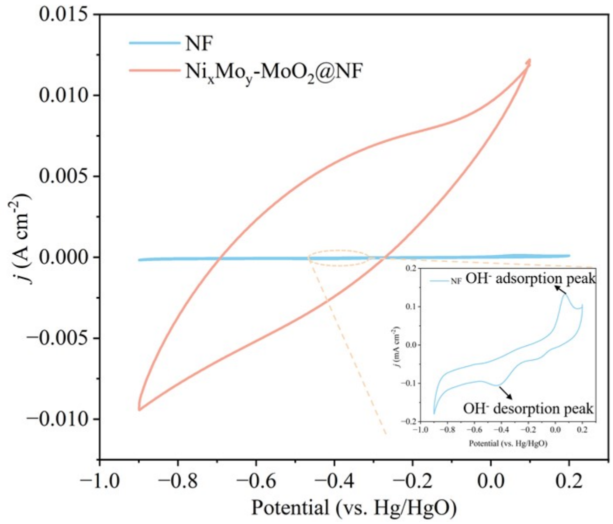

Figure S14. Analysis of the OH$^-$ desorption peaks in a 1 M NaOH solution.

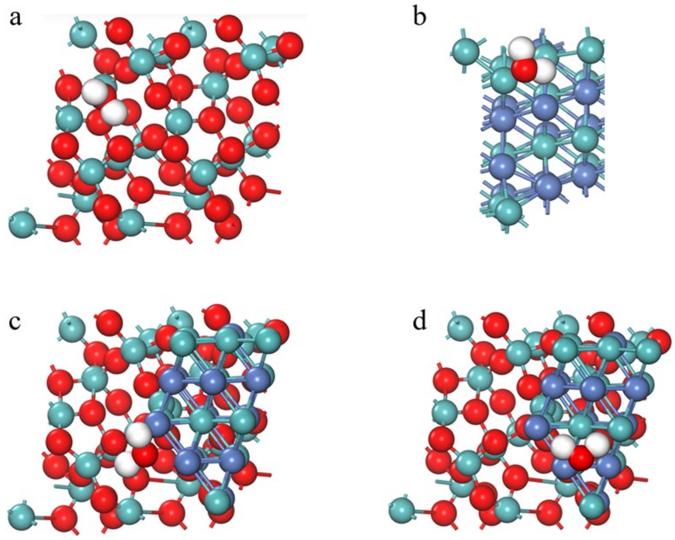

Figure S15. The optimized calculation models of water adsorption on (a) MoO_2, (b) NiMo, (c) Ni_xMo_y-MoO_2 (MoO_2) and (d) Ni_xMo_y-MoO_2 (NiMo).

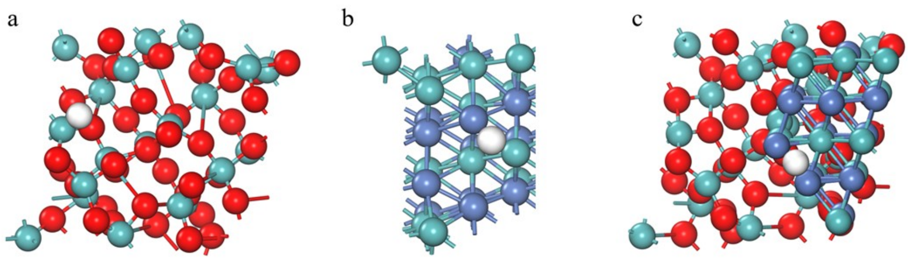

Figure S16. The optimized calculation models of H* adsorption on (a) MoO_2, (b) NiMo and (c) Ni_xMo_y-MoO_2.

a

b

c

IS TS FS

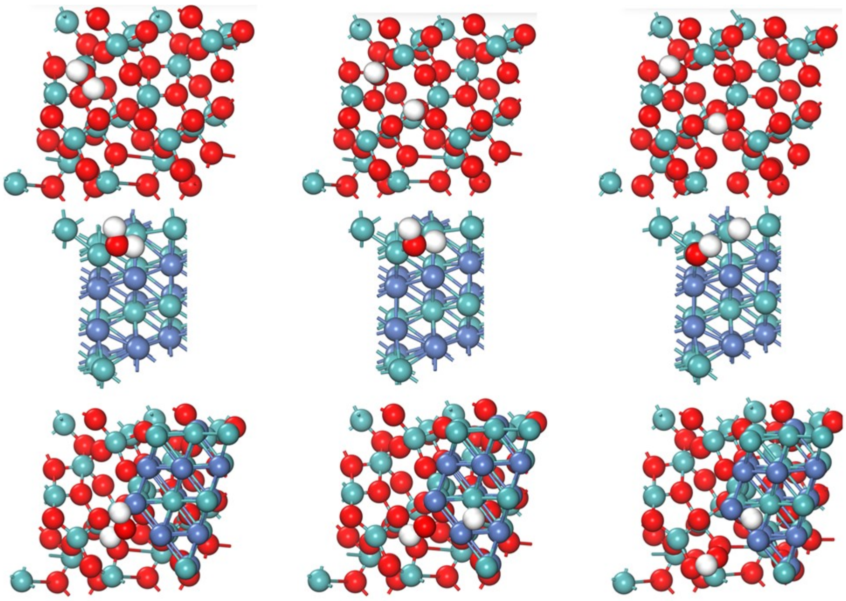

Figure S17. The reaction pathway of water dissociation for (a) MoO_2, (b) NiMo and (c) Ni_xMo_y-MoO_2.

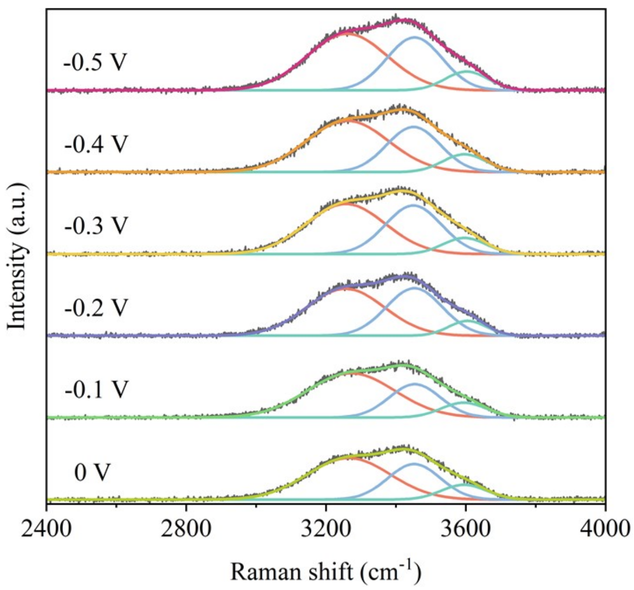

Figure S18. *In situ* Raman spectra of NF.

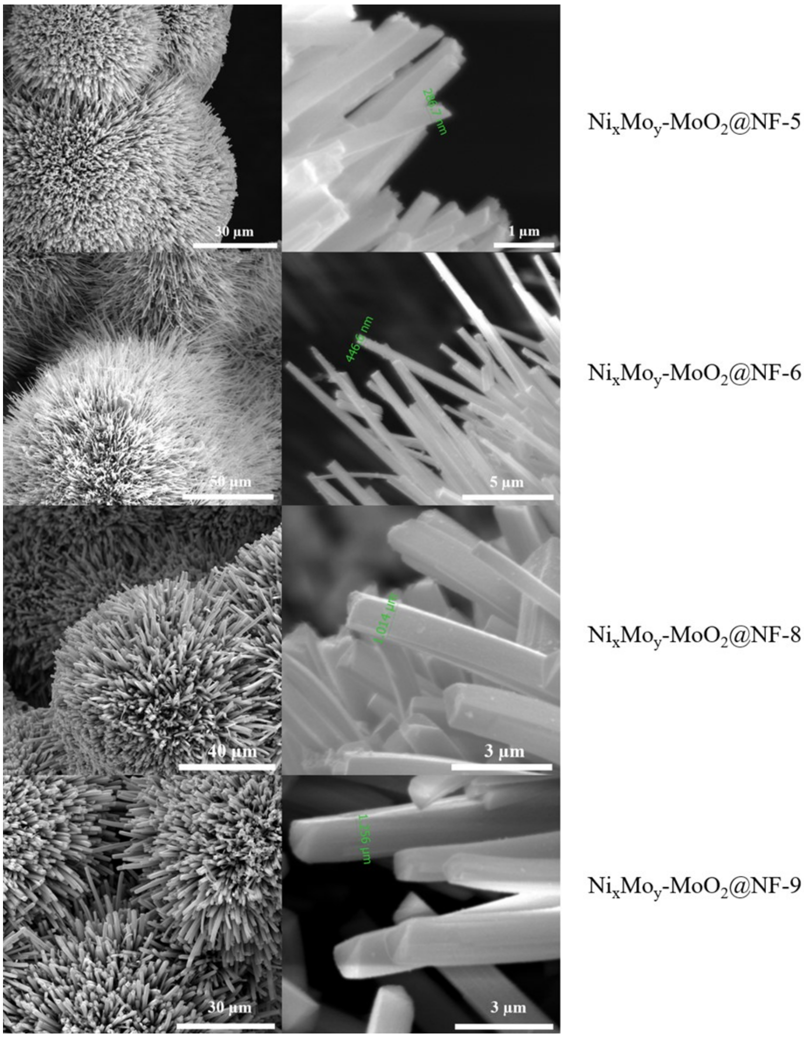

Figure S19. SEM images of Ni_xMo_y-MoO_2@NF synthesized under various pH conditions.

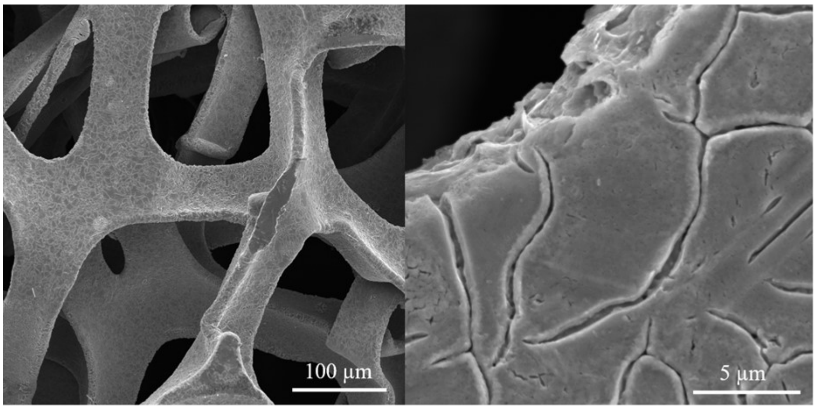

Figure S20. SEM images of Ni_xMo_y-MoO_2@NF-4.

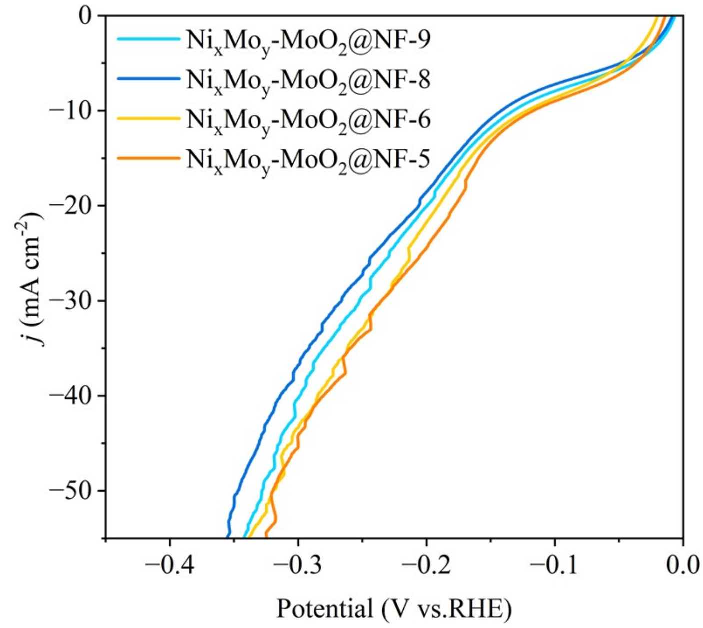

Figure S21. LSV curves of Ni_xMo_y-MoO_2@NF synthesized under various pH conditions.

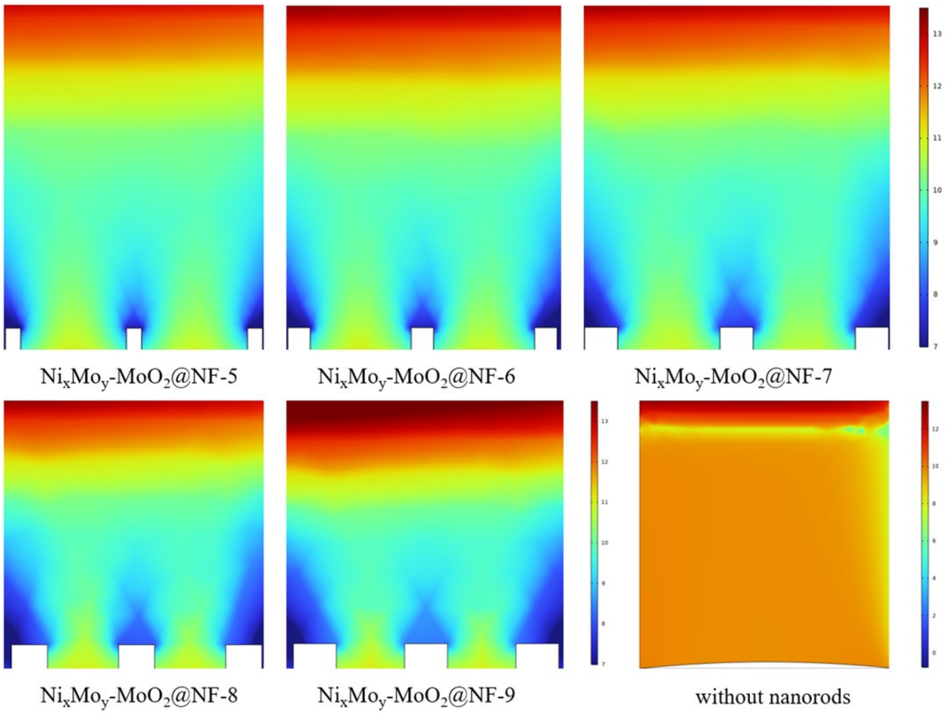

Figure S22. Distribution maps of the localized pH on the electrode surface.

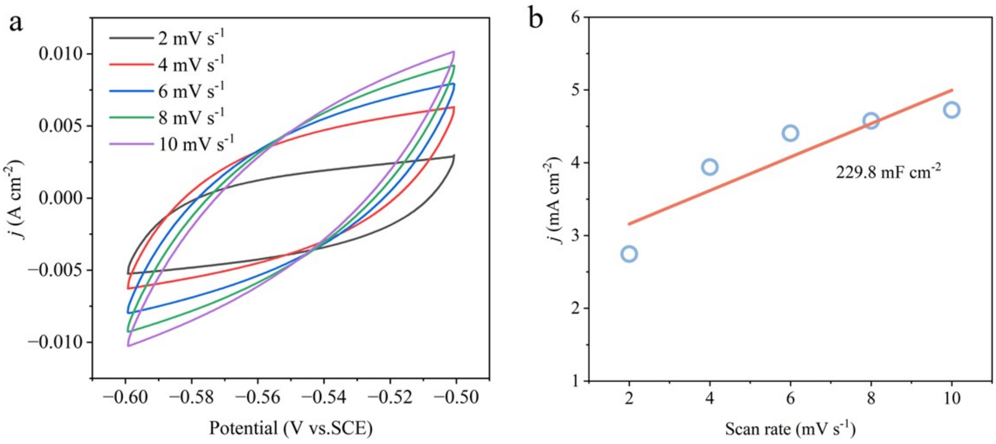

Figure S23. CV curves at various scan rates within the non-Faradaic potential region and the C_{dl} curves of Ni_xMo_y-MoO_2@NF-5 in natural seawater.

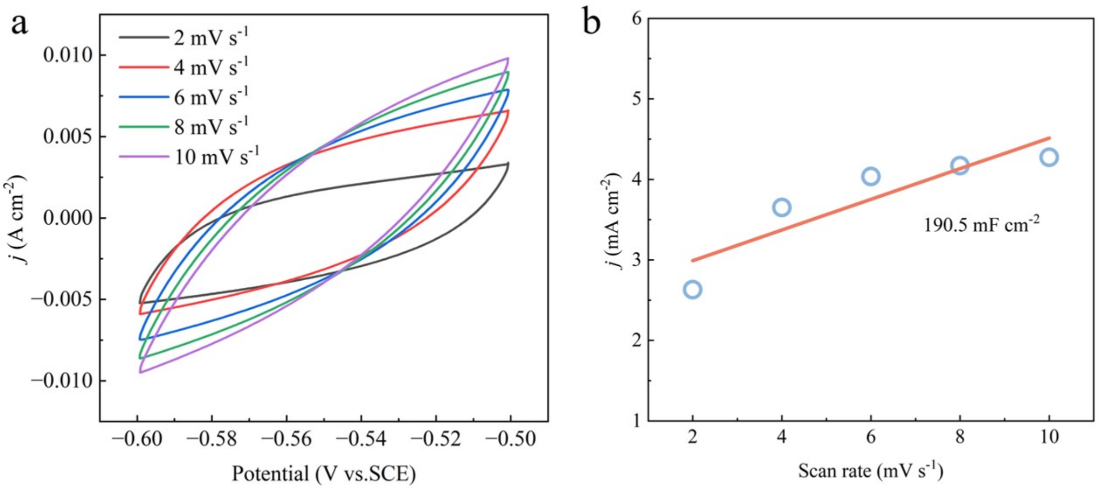

Figure S24. CV curves at various scan rates within the non-Faradaic potential region and the C_{dl} curves of Ni_xMo_y-MoO_2@NF-6 in natural seawater.

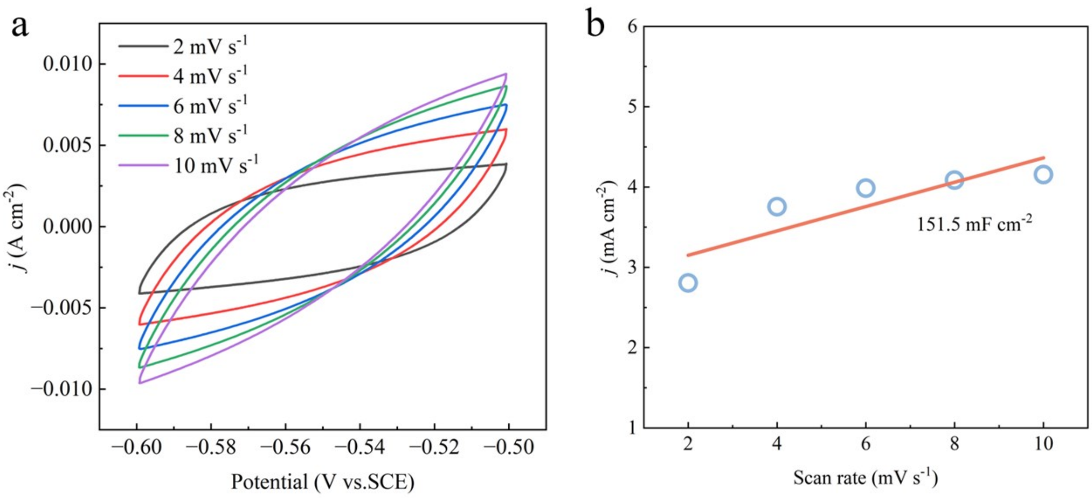

Figure S25. CV curves at various scan rates within the non-Faradaic potential region and the C_{dl} curves of Ni_xMo_y-MoO_2@NF-8 in natural seawater.

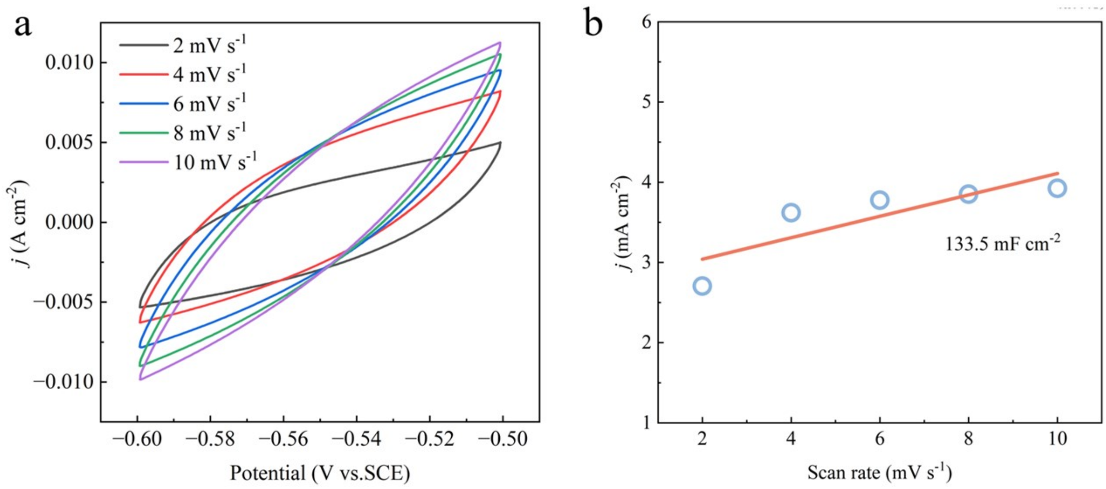

Figure S26. CV curves at various scan rates within the non-Faradaic potential region and the C_{dl} curves of Ni_xMo_y-MoO_2@NF-9 in natural seawater.

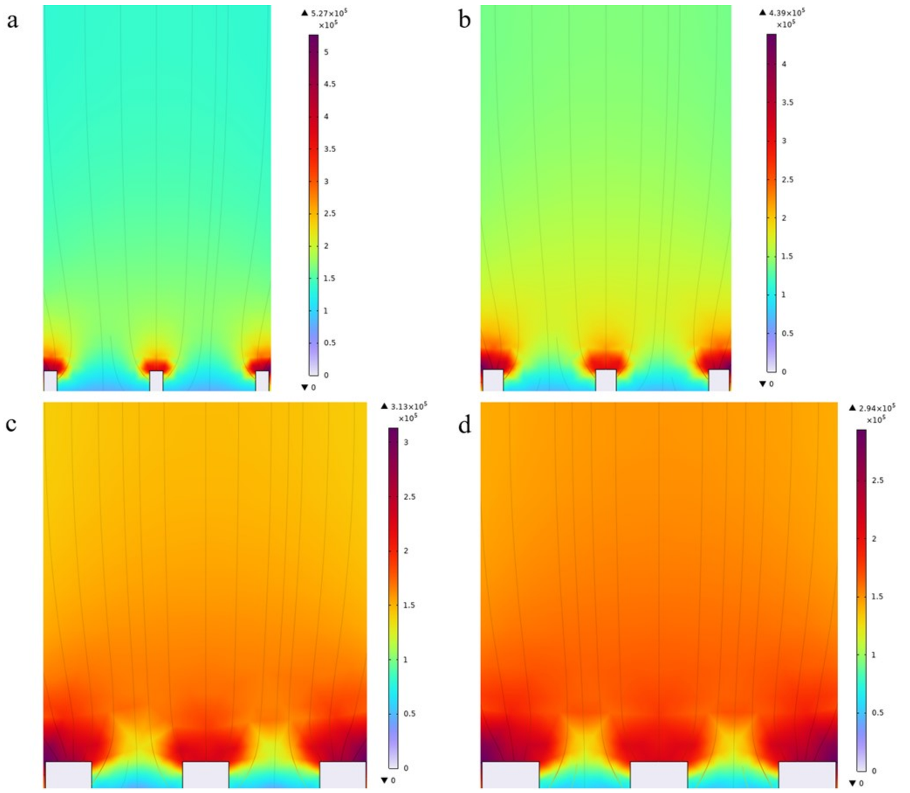

Figure S27. Surface electric field intensity distributions of (a) Ni_xMo_y-MoO_2@NF-5, (b) Ni_xMo_y-MoO_2@NF-6, (c) Ni_xMo_y-MoO_2@NF-8, and (d) Ni_xMo_y-MoO_2@NF-9.

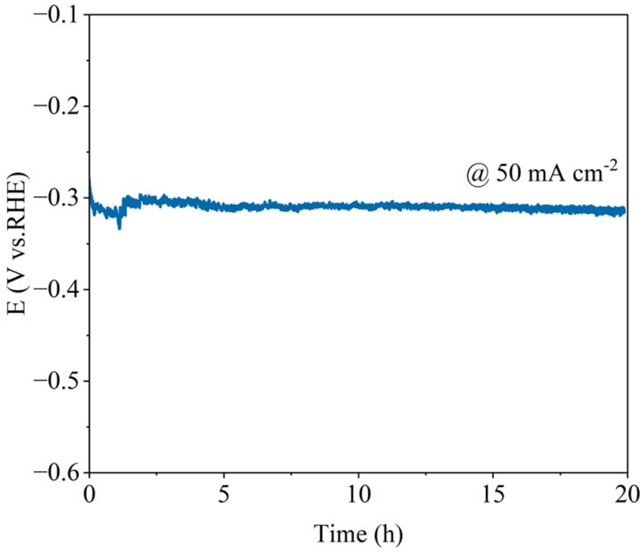

Figure S28. *E*–*t* curves of Ni_xMo_y-MoO_2@NF in natural seawater.

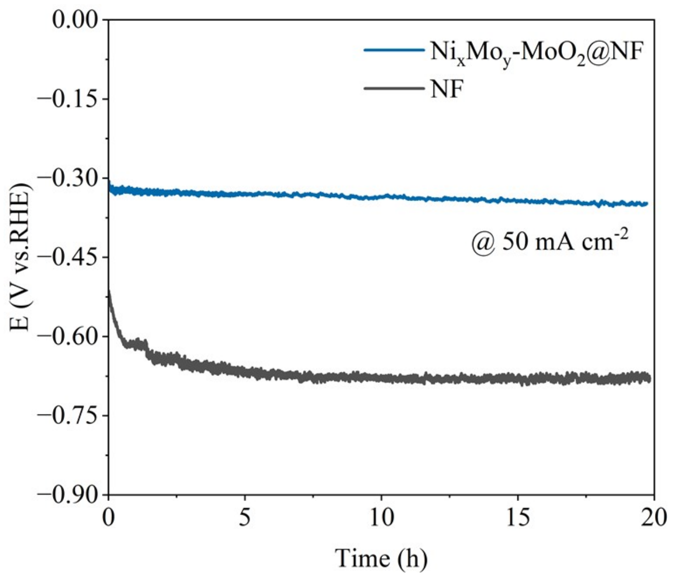

Figure S29. *E–t* curves of Ni_xMo_y-MoO_2@NF and NF in chloride-free artificial seawater.

The chloride-free artificial seawater was prepared by replacing the chloride ions in seawater with an equivalent amount of sulfate ions.

Table S1. Comparison of the HER performance for Ni_xMo_y-MoO_2@NF with other reported highly active HER electrocatalysts in nature seawater.

Electrocatalyst	Electrolyte	j (mA cm^{-2})	η (mV)	Ref.
Ni_xMo_y-MoO_2@NF	Seawater	10	123	This work
	Seawater	100	407	This work
Fe,P-$NiSe_2$ NFs	Seawater	10	170	Adv. Mater. 2021
Fe,P-$NiSe_2$ NFs	Seawater	100	645	Adv. Mater. 2021
CeO_2/α-MoC/β-MO_2C MRs/CC	Seawater	10	225	Appl. Catal. B Environ. 2022
NPNNS	Seawater	10	144	Appl. Catal. B Environ. 2019
Mo_5N_6	Seawater (Ar-saturated)	10	257	ACS Nano 2018
PtRuMo	Seawater	10	260	J. Mater. Chem. A 2016
0.5Rh-Gs1000	Seawater	10	320	ACS Sustainable Chem. Eng. 2019
Mn-NiO-Ni/Ni-F	Seawater	10	170	Energy Environ. Sci. 2018
NiCoP/NF	Seawater (pH=8.4)	10	287	ACS Appl. Energy Mater. 2019
NiCoN/NixP/NiCoN	Seawater	10	165	ACS Energy Lett. 2020
RuCo	Seawater	100	890	Electrochim. Acta 2016
NiMo@C_3N_5	Seawater (pH=7.4)	10	486	Chem. Eng. J. 2022
Fe–Co_2P BNRs	Seawater (pH=7.8)	10	489	J. Energy Chem. 2021
20% Pt/C	Seawater (pH=7.8)	10	749	J. Energy Chem. 2021
CoFeOF/NF	Seawater	10	162	Chem. Eng. J. 2024
$Co_{0.31}Mo_{1.69}C$/MXene/NC	Seawater	10	306	Adv. Energy Mater. 2019
Pt/C	Seawater	10	297	Adv. Energy Mater. 2019
CoMoP@C	Seawater	10	458	Energy Environ. Sci. 2017
20% Pt/C	Seawater	10	345	Energy Environ. Sci. 2017
40% Pt/C	Seawater	10	276	Energy Environ. Sci. 2017
PF-NiCoP/NF	Seawater	10	287	ACS Appl. Energy Mater. 2019
NiCoN|NixP|NiCoN	Seawater (pH=7.2)	10	165	ACS Energy Letters 2020
Pt/C	Seawater (pH=7.2)	10	90	ACS Energy Letters 2020
NF	Seawater (pH=7.2)	10	432	ACS Energy Letters 2020
Ni_5P_4@NiOOH	Seawater	10	144	Appl. Catal. B 2019

Mn doped Ni/NiO	Seawater	10	170	Energy Environ. Sci. 2018
Co_3Mo_3C/CNT	Seawater	10	170	RSC Adv. 2016
Pt-Ru-Mo	Seawater	10	196	J. Mater. Chem. A 2016
Rh/N,S-C	Seawater	10	320	ACS Sustainable Chem. Eng. 2019
Mo_2C/MoP/N,P-C	Seawater	10	346	Electrochim. Acta 2018
Ru-Co	Seawater	10	387	Electrochim. Acta 2016
Pt-NiCu alloy	Seawater	10	267	Nano Letters 2024
CoNiP/CoxP	Seawater	10	290	Small 2021
Pt/WO_2	Seawater	10	290	J. Am. Chem. Soc. 2024
Ru, W-$NiSe_2$/NF	Seawater	10	353	Int. J. of Hydrogen Energy 2023
C-WC-RuMg	Seawater	10	180	J. Mater. Chem. A 2024

Table S2. Comparison of the HER performance for Ni_xMo_y-MoO_2@NF with other reported highly active HER electrocatalysts in alkaline seawater.

Catalyst	Electrolyte	j (mA cm^{-2})	η (mV)	Ref
Ni_xMo_y-MoO_2@NF	1M KOH+seawater	100	83	This work
NiTe@FeOOH	1M KOH+seawater	100	280	Chem. Eng. J. 2023
Pt/C	1M KOH+seawater	100	164	Chem. Eng. J. 2023
S,P-(Ni,Mo,Fe)OOH/NiMoP/wood aerogel	1M KOH+seawater	100	212	Appl. Catal. B Environ. 2021
Ni@CNTs–MoxC/Ni_2P	1M KOH+seawater	100	180	Nano Energy 2023
Pt/C	1M KOH+seawater	100	96	Nano Energy 2023
NiFeS/NF	1M KOH+seawater	100	217	J. Mater. Chem. A 2023
Pt-Ni_3N@V_2O_3/NF (1.4 mg cm^{-2})	1M KOH+seawater	100	47	Sci. Adv. 2024
Pt-C/NF (1.4 mg cm^{-2})	1M KOH+seawater	100	109	Sci. Adv. 2024
Ni_3N@C/NF (4.0 mg cm^{-2})	1M KOH+seawater	100	142	J. Mater. Chem. A 2021
$Fe_{0.01}$-Ni&$Ni_{0.2}Mo_{0.8}N$	1M KOH+seawater	100	100	Energy Environ. Sci. 2022
NiCoHPi@Ni_3N/NF (5.4 mg cm^{-2})	1M KOH+seawater	100	182	ACS Appl. Mater. Interfaces 2022
NiMoN@NiFeN	1M KOH+seawater	100	82	Nat. Commun. 2019
NiPS/NF	1M KOH+seawater	100	329	J. Energy Chem. 2022
Fe/F-Ni_2P@NC	1M KOH+seawater	100	212	Chem. Eng. J. 2023
Ni-SA/NC (0.5 mg cm^{-2})	1M KOH+seawater	100	139	Adv. Mater. 2020
HPS−NiMo	Alkaline seawater	100	171	ACS Nano 2024
Fe_3Se_4/$NiSe_2$@Mxene	1M KOH+seawater	100	240	Adv. Funct. Mater. 2025

RuCo-$CoFe_2O_4$@IF	1M KOH+seawater	100	184	Chem. Eng. J. 2025
P-Fe_3O_4-x	1M KOH+seawater	100	200	Appl. Catal. B Environ. 2025
FeNiP-NPHC	1M KOH+seawater	100	180	Adv. Funct. Mater. 2022
Cr-Co_xP	1M KOH+seawater	100	194	Adv. Funct. Mater. 2023
Ni_2P-Fe_2P/NF	1M KOH+seawater	100	252	Adv. Funct. Mater. 2021
CoPGT	1 M KOH + 0.6 M NaCl	100	192	Nat. Commun. 2023

Table S3. The primary species and the corresponding contents in seawater.

Ions	Concentration (mmol/L)
Na^{+}	459.7
K^{+}	9.67
Mg^{2+}	50.7
Ca^{2+}	10.4
Cl^{-}	535.3
SO_4^{2-}	27
HCO_3^{-}	2.36

Table S4. EIS fitting parameters for the various electrodes.

Electrode	Rct
NF	43.490
Ni_xMo_y-MoO_2@NF	0.380
Ni_xMo_y-MoO_2@NF-5	0.330
Ni_xMo_y-MoO_2@NF-6	0.365
Ni_xMo_y-MoO_2@NF-8	0.392
Ni_xMo_y-MoO_2@NF-9	0.423
$NiMoO_x$@NF	89.600

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