

Supplementary Table S8. Benchmark results for the precision of CS prediction at four different tolerance windows. The bold value represents the highest precision among the predictors in a particular tolerance window. The SP type indicated with the symbol † represents SP types with limited training samples.

Method/backbone	Baseline	Fine-tuning			Prompt Tuning			Adapter Tuning			LoRA Tuning			
Organism	window	SignalP 6.0	ESM2-150M	ESM2-650M	ESM2-3B	ESM2-150M	ESM2-650M	ESM2-3B	ESM2-150M	ESM2-650M	ESM2-3B	ESM2-150M	ESM2-650M	ESM2-3B
Archaea Sec/SPI	±0	0.687	0.708	0.750	0.750	0.596	0.692	0.664	0.678	0.697	0.696	0.771	0.725	0.742
	±1	0.763	0.826	0.817	0.861	0.691	0.782	0.762	0.770	0.773	0.762	0.814	0.831	0.829
	±2	0.763	0.843	0.817	0.861	0.691	0.782	0.762	0.796	0.773	0.775	0.830	0.831	0.829
	±3	0.803	0.869	0.843	0.889	0.719	0.841	0.788	0.822	0.798	0.828	0.873	0.857	0.856
Archaea Sec/SPII	±0	0.883	0.864	0.917	0.889	0.597	0.606	0.540	0.917	0.850	0.778	0.917	0.736	0.744
	±1	0.883	0.864	0.917	0.889	0.597	0.606	0.540	0.917	0.850	0.778	0.917	0.736	0.744
	±2	0.883	0.864	0.917	0.889	0.597	0.606	0.540	0.917	0.850	0.778	0.917	0.736	0.744
	±3	0.883	0.864	0.917	0.889	0.597	0.606	0.564	0.917	0.850	0.778	0.917	0.736	0.744
Archaea Sec/SPIII †	±0	0.750	1.000	0.857	0.875	0.500	0.625	0.417	0.431	0.583	0.417	0.319	0.333	0.389
	±1	0.750	1.000	0.857	0.875	0.500	0.625	0.417	0.542	0.583	0.417	0.403	0.396	0.444
	±2	0.750	1.000	0.857	0.875	0.500	0.625	0.417	0.625	0.583	0.417	0.403	0.396	0.583
	±3	0.750	1.000	0.857	0.875	0.500	0.625	0.417	0.625	0.583	0.417	0.403	0.396	0.583
Archaea Tat/SPI	±0	0.469	0.400	0.500	0.427	0.113	0.287	0.209	0.323	0.550	0.525	0.418	0.306	0.417
	±1	0.562	0.492	0.583	0.521	0.146	0.350	0.321	0.469	0.683	0.617	0.547	0.398	0.444
	±2	0.562	0.492	0.625	0.521	0.235	0.433	0.321	0.469	0.683	0.617	0.547	0.417	0.514
	±3	0.656	0.567	0.771	0.635	0.247	0.483	0.370	0.625	0.833	0.721	0.659	0.500	0.618
Archaea Tat/SPII †	±0	0.562	0.854	0.783	0.754	0.393	0.417	0.190	0.822	0.867	0.583	0.933	0.817	0.750
	±1	0.688	0.854	0.783	0.754	0.393	0.417	0.190	0.822	0.867	0.583	0.933	0.817	0.750
	±2	0.688	0.854	0.783	0.754	0.393	0.417	0.190	0.822	0.867	0.583	0.933	0.817	0.750
	±3	0.688	0.854	0.783	0.754	0.393	0.417	0.190	0.822	0.867	0.583	0.933	0.900	0.750
Eukarya Sec/SPI	±0	0.813	0.828	0.827	0.817	0.796	0.816	0.838	0.811	0.821	0.834	0.826	0.756	0.818
	±1	0.854	0.863	0.864	0.855	0.831	0.849	0.870	0.850	0.858	0.869	0.863	0.808	0.857
	±2	0.895	0.890	0.897	0.885	0.861	0.876	0.897	0.881	0.888	0.898	0.896	0.858	0.891
	±3	0.916	0.908	0.912	0.901	0.876	0.890	0.912	0.900	0.903	0.913	0.911	0.880	0.910
Negative Sec/SPI	±0	0.708	0.709	0.704	0.690	0.580	0.642	0.626	0.705	0.731	0.706	0.746	0.688	0.707
	±1	0.735	0.741	0.728	0.716	0.601	0.660	0.640	0.740	0.751	0.731	0.774	0.720	0.736
	±2	0.743	0.752	0.740	0.731	0.610	0.666	0.646	0.746	0.756	0.739	0.787	0.734	0.743
	±3	0.747	0.759	0.748	0.738	0.612	0.670	0.648	0.754	0.759	0.744	0.794	0.738	0.750
Negative Sec/SPII	±0	0.955	0.936	0.972	0.970	0.896	0.898	0.908	0.968	0.958	0.969	0.965	0.960	0.965
	±1	0.956	0.936	0.972	0.970	0.896	0.898	0.910	0.968	0.958	0.969	0.966	0.960	0.965
	±2	0.956	0.936	0.972	0.970	0.896	0.899	0.910	0.968	0.958	0.969	0.966	0.961	0.965
	±3	0.957	0.937	0.972	0.971	0.897	0.900	0.912	0.969	0.959	0.969	0.967	0.961	0.966

Method/backbone		Baseline	Fine-tuning			Prompt Tuning			Adapter Tuning			LoRA Tuning		
Organism	window	SignalP 6.0	ESM2-150M	ESM2-650M	ESM2-3B	ESM2-150M	ESM2-650M	ESM2-3B	ESM2-150M	ESM2-650M	ESM2-3B	ESM2-150M	ESM2-650M	ESM2-3B
Negative Sec/SPIII †	±0	0.869	0.753	0.854	0.837	0.641	0.600	0.668	0.810	0.751	0.789	0.652	0.352	0.597
	±1	0.869	0.753	0.854	0.837	0.641	0.600	0.668	0.810	0.751	0.789	0.696	0.518	0.597
	±2	0.869	0.753	0.854	0.861	0.641	0.600	0.668	0.810	0.751	0.789	0.696	0.577	0.597
	±3	0.869	0.753	0.854	0.861	0.641	0.600	0.668	0.810	0.751	0.789	0.696	0.666	0.758
Negative Tat/SPI	±0	0.764	0.765	0.793	0.785	0.647	0.717	0.683	0.779	0.764	0.789	0.773	0.746	0.712
	±1	0.820	0.806	0.837	0.844	0.696	0.760	0.750	0.817	0.816	0.839	0.818	0.785	0.763
	±2	0.872	0.856	0.891	0.895	0.727	0.806	0.786	0.867	0.859	0.887	0.868	0.853	0.873
	±3	0.895	0.880	0.903	0.910	0.745	0.817	0.800	0.897	0.881	0.900	0.880	0.871	0.899
Negative Tat/SPII †	±0	0.362	0.301	0.266	0.322	0.056	0.167	0.175	0.346	0.311	0.326	0.282	0.321	0.525
	±1	0.438	0.301	0.266	0.322	0.056	0.167	0.175	0.346	0.311	0.326	0.282	0.321	0.525
	±2	0.438	0.301	0.266	0.322	0.056	0.177	0.175	0.346	0.311	0.326	0.282	0.321	0.525
	±3	0.438	0.301	0.266	0.322	0.056	0.177	0.175	0.346	0.311	0.326	0.282	0.321	0.525
Positive Sec/SPI	±0	0.671	0.723	0.758	0.668	0.520	0.580	0.611	0.705	0.684	0.674	0.728	0.679	0.715
	±1	0.684	0.735	0.768	0.686	0.524	0.588	0.622	0.720	0.709	0.696	0.740	0.691	0.734
	±2	0.700	0.752	0.787	0.702	0.541	0.601	0.633	0.736	0.726	0.711	0.763	0.710	0.755
	±3	0.710	0.757	0.792	0.712	0.549	0.606	0.638	0.741	0.731	0.717	0.771	0.724	0.763
Positive Sec/SPII	±0	0.964	0.972	0.977	0.980	0.931	0.933	0.941	0.974	0.968	0.978	0.964	0.964	0.974
	±1	0.964	0.972	0.977	0.980	0.933	0.933	0.941	0.974	0.968	0.978	0.964	0.964	0.974
	±2	0.965	0.972	0.977	0.980	0.933	0.933	0.941	0.974	0.968	0.978	0.964	0.964	0.974
	±3	0.965	0.972	0.977	0.980	0.933	0.933	0.941	0.974	0.968	0.978	0.964	0.964	0.974
Positive Sec/SPIII †	±0	0.944	0.917	0.917	1.000	0.595	0.647	0.508	0.889	1.000	0.944	0.650	0.500	0.733
	±1	0.944	0.917	0.917	1.000	0.595	0.647	0.508	0.889	1.000	0.944	0.817	0.583	0.733
	±2	0.944	0.917	0.917	1.000	0.595	0.647	0.508	0.889	1.000	0.944	0.817	0.750	0.733
	±3	0.944	0.917	0.917	1.000	0.595	0.647	0.508	0.889	1.000	0.944	0.817	0.750	0.900
Positive Tat/SPI	±0	0.518	0.687	0.598	0.634	0.369	0.301	0.267	0.542	0.553	0.623	0.594	0.455	0.611
	±1	0.595	0.687	0.630	0.634	0.369	0.320	0.297	0.553	0.553	0.665	0.616	0.476	0.611
	±2	0.921	0.975	0.882	0.903	0.485	0.478	0.486	0.906	0.769	0.958	0.912	0.727	0.889
	±3	0.921	0.975	0.905	0.958	0.559	0.478	0.486	0.906	0.769	0.958	0.912	0.727	0.889
Positive Tat/SPII †	±0	0.639	0.428	0.467	0.436	0.329	0.137	0.117	0.621	0.573	0.550	0.767	0.521	0.641
	±1	0.639	0.461	0.467	0.436	0.329	0.137	0.117	0.621	0.573	0.550	0.767	0.521	0.641
	±2	0.639	0.461	0.467	0.436	0.329	0.137	0.117	0.621	0.573	0.550	0.767	0.521	0.641
	±3	0.639	0.461	0.467	0.436	0.329	0.137	0.117	0.621	0.573	0.550	0.767	0.521	0.641
mean		0.767	0.773	0.777	0.772	0.558	0.592	0.550	0.752	0.758	0.730	0.752	0.673	0.733