

Table 1. Macro Performance Metrics for Bayesian—Scikit Optimization

K	Mean Accuracy ± Std	Mean Precision ± Std	Mean Recall ± Std	Mean F1 ± Std
3	0.851 ± 0.004	0.859 ± 0.003	0.832 ± 0.004	0.840 ± 0.001
4	0.849 ± 0.019	0.852 ± 0.022	0.836 ± 0.024	0.842 ± 0.021
5	0.812 ± 0.030	0.809 ± 0.048	0.801 ± 0.021	0.800 ± 0.030
6	0.844 ± 0.017	0.843 ± 0.021	0.837 ± 0.015	0.836 ± 0.016
7	0.824 ± 0.015	0.823 ± 0.020	0.823 ± 0.020	0.819 ± 0.017
8	0.831 ± 0.016	0.830 ± 0.018	0.827 ± 0.022	0.826 ± 0.017
9	0.850 ± 0.028	0.855 ± 0.030	0.834 ± 0.041	0.840 ± 0.033
10	0.830 ± 0.020	0.830 ± 0.030	0.826 ± 0.019	0.824 ± 0.021

Table 2. Per-Class Performance Metrics for Bayesian—Scikit Optimization

K	Class	Mean Precision ± Std	Mean Recall ± Std	Mean F1 ± Std
3	Benign	0.836 ± 0.007	0.915 ± 0.007	0.874 ± 0.007
	Malignant	0.920 ± 0.029	0.708 ± 0.015	0.800 ± 0.005
	Normal	0.822 ± 0.027	0.873 ± 0.022	0.846 ± 0.008
4	Benign	0.846 ± 0.017	0.893 ± 0.021	0.868 ± 0.015
	Malignant	0.844 ± 0.051	0.757 ± 0.041	0.798 ± 0.045
	Normal	0.866 ± 0.025	0.857 ± 0.089	0.860 ± 0.056
5	Benign	0.853 ± 0.021	0.841 ± 0.062	0.846 ± 0.026
	Malignant	0.781 ± 0.108	0.762 ± 0.047	0.766 ± 0.046
	Normal	0.791 ± 0.104	0.800 ± 0.070	0.787 ± 0.029
6	Benign	0.846 ± 0.012	0.878 ± 0.027	0.862 ± 0.016
	Malignant	0.892 ± 0.050	0.760 ± 0.023	0.820 ± 0.027
	Normal	0.791 ± 0.051	0.873 ± 0.044	0.827 ± 0.024
7	Benign	0.833 ± 0.020	0.857 ± 0.032	0.844 ± 0.013
	Malignant	0.806 ± 0.052	0.700 ± 0.058	0.746 ± 0.030
	Normal	0.830 ± 0.041	0.911 ± 0.040	0.867 ± 0.021
8	Benign	0.840 ± 0.024	0.861 ± 0.030	0.850 ± 0.016
	Malignant	0.827 ± 0.049	0.750 ± 0.041	0.785 ± 0.033
	Normal	0.823 ± 0.055	0.869 ± 0.057	0.843 ± 0.046
9	Benign	0.845 ± 0.039	0.901 ± 0.045	0.871 ± 0.025
	Malignant	0.885 ± 0.052	0.739 ± 0.055	0.803 ± 0.029
	Normal	0.835 ± 0.058	0.862 ± 0.096	0.845 ± 0.056
10	Benign	0.843 ± 0.023	0.858 ± 0.040	0.850 ± 0.019
	Malignant	0.821 ± 0.064	0.743 ± 0.033	0.778 ± 0.022
	Normal	0.821 ± 0.065	0.876 ± 0.044	0.844 ± 0.028

Table 3. Macro Performance Metrics for Bayesian—Optuna

K	Mean Accuracy ± Std	Mean Precision ± Std	Mean Recall ± Std	Mean F1 ± Std
3	0.845 ± 0.025	0.847 ± 0.024	0.837 ± 0.038	0.840 ± 0.031
4	0.864 ± 0.017	0.873 ± 0.025	0.852 ± 0.023	0.859 ± 0.020
5	0.831 ± 0.025	0.832 ± 0.031	0.827 ± 0.025	0.824 ± 0.025
6	0.859 ± 0.022	0.862 ± 0.025	0.853 ± 0.024	0.855 ± 0.022
7	0.857 ± 0.014	0.872 ± 0.023	0.840 ± 0.028	0.852 ± 0.017
8	0.834 ± 0.010	0.830 ± 0.015	0.832 ± 0.012	0.826 ± 0.015
9	0.822 ± 0.028	0.827 ± 0.029	0.808 ± 0.041	0.815 ± 0.033
10	0.851 ± 0.022	0.865 ± 0.026	0.829 ± 0.030	0.843 ± 0.027

Table 4. Per-Class Performance Metrics for Bayesian—Optuna

K	Class	Mean Precision ± Std	Mean Recall ± Std	Mean F1 ± Std
3	Benign	0.846 ± 0.040	0.889 ± 0.013	0.866 ± 0.021
	Malignant	0.832 ± 0.019	0.718 ± 0.051	0.770 ± 0.024
	Normal	0.863 ± 0.064	0.905 ± 0.078	0.883 ± 0.069
4	Benign	0.852 ± 0.012	0.917 ± 0.032	0.883 ± 0.016
	Malignant	0.881 ± 0.042	0.734 ± 0.015	0.800 ± 0.019
	Normal	0.885 ± 0.037	0.905 ± 0.075	0.892 ± 0.038
5	Benign	0.843 ± 0.024	0.860 ± 0.055	0.850 ± 0.027
	Malignant	0.848 ± 0.079	0.750 ± 0.034	0.793 ± 0.030
	Normal	0.803 ± 0.090	0.866 ± 0.070	0.829 ± 0.051
6	Benign	0.858 ± 0.018	0.894 ± 0.027	0.875 ± 0.017
	Malignant	0.863 ± 0.066	0.760 ± 0.047	0.806 ± 0.040
	Normal	0.865 ± 0.035	0.904 ± 0.048	0.883 ± 0.027
7	Benign	0.848 ± 0.030	0.904 ± 0.045	0.873 ± 0.013
	Malignant	0.859 ± 0.062	0.772 ± 0.043	0.810 ± 0.019
	Normal	0.909 ± 0.047	0.843 ± 0.087	0.871 ± 0.042
8	Benign	0.849 ± 0.016	0.871 ± 0.024	0.859 ± 0.008
	Malignant	0.843 ± 0.062	0.703 ± 0.038	0.764 ± 0.029
	Normal	0.798 ± 0.077	0.923 ± 0.047	0.853 ± 0.056
9	Benign	0.826 ± 0.041	0.864 ± 0.032	0.844 ± 0.027
	Malignant	0.794 ± 0.050	0.739 ± 0.044	0.763 ± 0.013
	Normal	0.861 ± 0.062	0.820 ± 0.114	0.837 ± 0.078
10	Benign	0.840 ± 0.029	0.911 ± 0.029	0.873 ± 0.018
	Malignant	0.842 ± 0.047	0.743 ± 0.070	0.787 ± 0.040
	Normal	0.913 ± 0.053	0.833 ± 0.071	0.870 ± 0.052

Table 5. Macro Performance Metrics for Bayesian—GPyOpt

K	Mean Accuracy ± Std	Mean Precision ± Std	Mean Recall ± Std	Mean F1 ± Std
3	0.778 ± 0.027	0.781 ± 0.019	0.758 ± 0.022	0.767 ± 0.022
4	0.800 ± 0.019	0.804 ± 0.041	0.769 ± 0.007	0.782 ± 0.019
5	0.843 ± 0.006	0.845 ± 0.004	0.834 ± 0.022	0.840 ± 0.012
6	0.831 ± 0.016	0.838 ± 0.021	0.812 ± 0.024	0.822 ± 0.019
7	0.832 ± 0.018	0.845 ± 0.026	0.812 ± 0.029	0.823 ± 0.020
8	0.834 ± 0.030	0.843 ± 0.034	0.810 ± 0.029	0.824 ± 0.031
9	0.846 ± 0.020	0.849 ± 0.029	0.845 ± 0.025	0.840 ± 0.022
10	0.838 ± 0.020	0.842 ± 0.028	0.832 ± 0.017	0.834 ± 0.018

Table 6. Per-Class Performance Metrics for Bayesian—GPyOpt

K	Class	Mean Precision ± Std	Mean Recall ± Std	Mean F1 ± Std
3	Benign	0.809 ± 0.008	0.830 ± 0.040	0.819 ± 0.023
	Malignant	0.693 ± 0.082	0.700 ± 0.015	0.693 ± 0.048
	Normal	0.841 ± 0.034	0.746 ± 0.022	0.790 ± 0.008
4	Benign	0.816 ± 0.027	0.869 ± 0.052	0.840 ± 0.020
	Malignant	0.761 ± 0.079	0.710 ± 0.026	0.732 ± 0.032
	Normal	0.837 ± 0.090	0.726 ± 0.021	0.774 ± 0.031
5	Benign	0.841 ± 0.026	0.879 ± 0.024	0.859 ± 0.002
	Malignant	0.876 ± 0.061	0.756 ± 0.041	0.809 ± 0.026
	Normal	0.820 ± 0.049	0.867 ± 0.063	0.842 ± 0.051
6	Benign	0.830 ± 0.020	0.886 ± 0.035	0.856 ± 0.018
	Malignant	0.823 ± 0.057	0.740 ± 0.029	0.779 ± 0.035
	Normal	0.860 ± 0.048	0.809 ± 0.080	0.831 ± 0.050
7	Benign	0.831 ± 0.028	0.884 ± 0.048	0.856 ± 0.017
	Malignant	0.813 ± 0.072	0.754 ± 0.045	0.780 ± 0.031
	Normal	0.891 ± 0.035	0.796 ± 0.100	0.835 ± 0.045
8	Benign	0.826 ± 0.022	0.897 ± 0.041	0.860 ± 0.025
	Malignant	0.842 ± 0.083	0.730 ± 0.038	0.780 ± 0.051
	Normal	0.862 ± 0.060	0.803 ± 0.044	0.831 ± 0.046
9	Benign	0.857 ± 0.026	0.880 ± 0.043	0.867 ± 0.019
	Malignant	0.872 ± 0.078	0.729 ± 0.059	0.789 ± 0.022
	Normal	0.817 ± 0.078	0.925 ± 0.068	0.863 ± 0.041
10	Benign	0.849 ± 0.029	0.874 ± 0.053	0.860 ± 0.020
	Malignant	0.822 ± 0.084	0.740 ± 0.044	0.774 ± 0.033
	Normal	0.856 ± 0.053	0.881 ± 0.049	0.866 ± 0.034

Table 7. Macro Performance Metrics for TPE—Optuna

K	Mean Accuracy ± Std	Mean Precision ± Std	Mean Recall ± Std	Mean F1 ± Std
3	0.844 ± 0.014	0.846 ± 0.021	0.835 ± 0.013	0.834 ± 0.014
4	0.844 ± 0.018	0.843 ± 0.028	0.851 ± 0.004	0.840 ± 0.017
5	0.816 ± 0.008	0.815 ± 0.014	0.809 ± 0.007	0.810 ± 0.008
6	0.859 ± 0.018	0.871 ± 0.022	0.841 ± 0.022	0.852 ± 0.019
7	0.828 ± 0.015	0.833 ± 0.026	0.821 ± 0.023	0.822 ± 0.014
8	0.831 ± 0.019	0.833 ± 0.028	0.827 ± 0.022	0.827 ± 0.021
9	0.852 ± 0.017	0.858 ± 0.024	0.840 ± 0.023	0.845 ± 0.023
10	0.828 ± 0.021	0.828 ± 0.032	0.813 ± 0.025	0.818 ± 0.026

Table 8. Per-Class Performance Metrics for TPE—Optuna

K	Class	Mean Precision ± Std	Mean Recall ± Std	Mean F1 ± Std
3	Benign	0.845 ± 0.006	0.894 ± 0.027	0.868 ± 0.014
	Malignant	0.897 ± 0.044	0.708 ± 0.015	0.790 ± 0.008
	Normal	0.795 ± 0.052	0.905 ± 0.039	0.845 ± 0.026
4	Benign	0.859 ± 0.012	0.865 ± 0.053	0.860 ± 0.021
	Malignant	0.869 ± 0.065	0.734 ± 0.047	0.793 ± 0.026
	Normal	0.801 ± 0.073	0.952 ± 0.033	0.867 ± 0.038
5	Benign	0.834 ± 0.022	0.844 ± 0.023	0.839 ± 0.013
	Malignant	0.769 ± 0.063	0.743 ± 0.023	0.754 ± 0.020
	Normal	0.842 ± 0.056	0.838 ± 0.023	0.839 ± 0.029
6	Benign	0.857 ± 0.025	0.910 ± 0.035	0.881 ± 0.012
	Malignant	0.840 ± 0.077	0.770 ± 0.029	0.801 ± 0.032
	Normal	0.910 ± 0.022	0.841 ± 0.065	0.874 ± 0.038
7	Benign	0.832 ± 0.032	0.868 ± 0.041	0.849 ± 0.016
	Malignant	0.846 ± 0.061	0.723 ± 0.035	0.779 ± 0.040
	Normal	0.819 ± 0.097	0.870 ± 0.079	0.837 ± 0.049
8	Benign	0.839 ± 0.024	0.865 ± 0.050	0.851 ± 0.021
	Malignant	0.831 ± 0.067	0.730 ± 0.038	0.774 ± 0.021
	Normal	0.829 ± 0.063	0.886 ± 0.063	0.854 ± 0.041
9	Benign	0.846 ± 0.015	0.901 ± 0.018	0.872 ± 0.013
	Malignant	0.872 ± 0.049	0.736 ± 0.030	0.797 ± 0.017
	Normal	0.854 ± 0.049	0.884 ± 0.068	0.867 ± 0.041
10	Benign	0.839 ± 0.022	0.879 ± 0.039	0.857 ± 0.012
	Malignant	0.811 ± 0.074	0.721 ± 0.026	0.762 ± 0.037
	Normal	0.835 ± 0.081	0.838 ± 0.077	0.834 ± 0.064

Table 9. Macro Performance Metrics for TPE—Hyperopt

K	Mean Accuracy ± Std	Mean Precision ± Std	Mean Recall ± Std	Mean F1 ± Std
3	0.842 ± 0.018	0.840 ± 0.015	0.856 ± 0.009	0.844 ± 0.014
4	0.844 ± 0.015	0.847 ± 0.016	0.834 ± 0.017	0.839 ± 0.017
5	0.829 ± 0.014	0.828 ± 0.022	0.817 ± 0.018	0.818 ± 0.018
6	0.861 ± 0.021	0.868 ± 0.026	0.850 ± 0.021	0.856 ± 0.023
7	0.833 ± 0.018	0.843 ± 0.025	0.810 ± 0.024	0.822 ± 0.020
8	0.834 ± 0.024	0.832 ± 0.029	0.831 ± 0.029	0.829 ± 0.028
9	0.817 ± 0.022	0.813 ± 0.022	0.821 ± 0.024	0.811 ± 0.025
10	0.847 ± 0.020	0.849 ± 0.030	0.836 ± 0.028	0.839 ± 0.024

Table 10. Per-Class Performance Metrics for TPE—Hyperopt

K	Class	Mean Precision ± Std	Mean Recall ± Std	Mean F1 ± Std
3	Benign	0.885 ± 0.030	0.831 ± 0.060	0.854 ± 0.023
	Malignant	0.767 ± 0.066	0.802 ± 0.078	0.778 ± 0.011
	Normal	0.867 ± 0.003	0.936 ± 0.022	0.900 ± 0.012
4	Benign	0.849 ± 0.025	0.889 ± 0.011	0.868 ± 0.017
	Malignant	0.820 ± 0.039	0.734 ± 0.034	0.774 ± 0.017
	Normal	0.872 ± 0.048	0.881 ± 0.023	0.876 ± 0.033
5	Benign	0.832 ± 0.011	0.882 ± 0.024	0.856 ± 0.015
	Malignant	0.857 ± 0.038	0.693 ± 0.046	0.764 ± 0.022
	Normal	0.794 ± 0.058	0.876 ± 0.071	0.832 ± 0.057
6	Benign	0.855 ± 0.019	0.904 ± 0.029	0.879 ± 0.020
	Malignant	0.864 ± 0.065	0.775 ± 0.028	0.804 ± 0.027
	Normal	0.885 ± 0.058	0.889 ± 0.035	0.886 ± 0.039
7	Benign	0.824 ± 0.025	0.897 ± 0.033	0.858 ± 0.014
	Malignant	0.876 ± 0.086	0.723 ± 0.039	0.789 ± 0.037
	Normal	0.827 ± 0.047	0.809 ± 0.056	0.817 ± 0.043
8	Benign	0.840 ± 0.021	0.865 ± 0.025	0.852 ± 0.019
	Malignant	0.840 ± 0.053	0.734 ± 0.031	0.781 ± 0.022
	Normal	0.816 ± 0.054	0.892 ± 0.066	0.852 ± 0.054
9	Benign	0.841 ± 0.021	0.839 ± 0.045	0.839 ± 0.020
	Malignant	0.813 ± 0.063	0.708 ± 0.055	0.754 ± 0.032
	Normal	0.787 ± 0.084	0.915 ± 0.062	0.840 ± 0.044
10	Benign	0.858 ± 0.035	0.890 ± 0.039	0.872 ± 0.016
	Malignant	0.837 ± 0.065	0.747 ± 0.043	0.787 ± 0.023
	Normal	0.853 ± 0.060	0.871 ± 0.071	0.858 ± 0.038